JOINT MONITORING PROGRAM IN THE CHUKCHI AND BEAUFORT SEAS, OPEN WATER SEASONS, 2006–2007

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for

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ConocoPhillips Alaska, Inc.

and

National Marine Fisheries Service
United States Fish and Wildlife Service

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LIST OF ACRONYMS AND ABBREVIATIONS

~	approximately
ADC	analog to digital converter
AEWC	Alaska Eskimo Whaling Commission
Ah	ampere–hours
ASL	above sea level
Bf	Beaufort Wind Force
BOWFEST	bowhead whale feeding ecology
BPXA	BP Exploration (Alaska) Inc.
BWASP	bowhead whale aerial survey program
CAA	Conflict Avoidance Agreement
cm	centimeter
COTS	commercial–off–the–shelf
CPA	Closest (Observed) Point of Approach
CPAI	ConocoPhillips Alaska, Inc.
CTD	conductivity, temperature, depth
DASAR	Directional Autonomous Seafloor Acoustic Recorders
dB	decibel
DSP	digital signal processing
ESA	(U.S.) Endangered Species Act
ESW	effective strip half–width
f(0)	sighting probability density at zero perpendicular distance from survey track; equivalently, 1/(effective strip width)
FFT	fast Fourier transform
ft	feet
GB	giga byte (1024 ^ 3)
GMT	Greenwich Mean Time
GPS	Global Positioning System
g(0)	probability of seeing a group located directly on a survey line
GXT	GX Technology
h	hours
hp	horse power
Hz	Hertz (cycles per second)
IHA	Incidental Harassment Authorization (under U.S. MMPA)
IDE	integrated development environment
in^3	cubic inches
JMP	Joint Monitoring Program
JNI	Java native interface
kHz	kilohertz
km	kilometer
km^2	square kilometers
km/h	kilometers per hour
kt	knots
µPa	micro Pascal

m	meters
mi	statute mile
min	minutes
MMS	Minerals Management Service
MMO	Marine Mammal Observer
MMPA	(U.S.) Marine Mammal Protection Act
n	sample size
n.mi.	nautical miles
NMFS	(U.S.) National Marine Fisheries Service
NMML	National Marine Mammal Lab
No.	number
NOAA	National Oceanic and Atmospheric Administration
NSB	North Slope Borough
OBH	ocean bottom hydrophone
ODS	Oooguruk Drilling Site
OS	operating system
PDF	probability density function
pk–pk	peak–to–peak
re	in reference to
rms	root–mean–square: an average, in the present context over the duration of a sound pulse
ROC	receiver operating characteristic
ROV	remote operated vehicle
s	seconds
s.d.	standard deviation
SEL	Sound Exposure Level: a measure of energy content, in dB re 1 $\mu Pa^2 \cdot s$
SNACS	Study of Northern Alaska Coastal Systems
SOI	Shell Offshore, Inc.
SPL	Sound Pressure Level; the SPL for a seismic pulse is equivalent to its rms level
USFWS	United States Fish and Wildlife Service
XML	extendible markup language
yd	yard

EXECUTIVE SUMMARY

Chapter 1: Introduction and Report Objectives

This report describes the results of studies conducted by Shell Offshore, Inc. (SOI), in conjunction with ConocoPhillips Alaska, Inc. (CPAI), during seismic activities in 2007, as well as other offshore activities that occurred in the Chukchi and Beaufort seas during the open–water period from Jul through Nov. Mitigation and monitoring during seismic exploration activities were conducted in a relatively small portion of the MMS Chukchi Sea Lease Sale Area 193 and in the vicinity of specific lease holdings in the Beaufort Sea. Studies included vessel–based monitoring and mitigation programs in the Chukchi and Beaufort seas, and an aerial–based monitoring and mitigation program in the Beaufort Sea. Research programs were conducted over a much larger area in the both the Chukchi and Beaufort seas. The Chukchi Sea research program included an aerial monitoring component over the nearshore waters to ~32 km (20 mi) offshore of the Chukchi Sea coast between Pt. Hope and Barrow, and an acoustic component using arrays of bottom–founded recorders deployed relatively close to the coast and in areas further offshore. During the research program in the Beaufort Sea, five arrays of directional recorders were used to monitor marine mammal (primarily bowhead whale) calling behavior relative to seismic activities.

The objectives of the report are

- to provide data to begin to fill current gaps in our understanding of the relative abundance and distribution of marine mammals in the Chukchi and Beaufort seas; and
- to assess the potential impacts of seismic activity on marine mammals in the Chukchi and Beaufort seas.

To the extent possible, the report integrates the studies conducted as part of the monitoring program into a broad–based assessment of industry activities and their impacts on marine mammals in the Chukchi and Beaufort seas during 2007. As part of this integration, monitoring and mitigation data collected in 2006 and 2007 were combined when appropriate to allow a more comprehensive analysis of marine mammal distribution and density in the Chukchi and Beaufort seas. The report also describes other known industry and human activities occurring offshore in the Chukchi and Beaufort seas during 2007 focusing on the potential impacts to marine mammals from underwater sound associated with various industry activities and related vessel traffic. The results of other industry and agency studies of marine mammals in the Beaufort and Chukchi seas in 2007 are also discussed.

Chapter 2: Industry and Other Human Activities

Vessel–based seismic exploration involves the use of airgun arrays that emit sound energy into the water which has the potential to result in “takes” of marine mammals as defined by the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS). SOI applied for and received Incidental Harassment Authorizations (IHAs) from the NMFS and the USFWS that contained specific monitoring and mitigation measures designed to minimize such “take.” A vessel–based marine mammal monitoring and mitigation program and an aerial survey program were developed to implement the requirements of the IHAs. This chapter describes the timing of SOI’s exploration activities and other industry and human activities in the Chukchi Sea in 2007 followed by a description of similar types of activities in the Beaufort Sea.

Chukchi Sea

The seismic source vessel *Gilavar* entered the Chukchi Sea on 21 Jul 2007. Measurements of the sounds produced from the airgun array and the single mitigation airgun were performed on 28–29 Aug. SOI used a 3147 in^3 three–string airgun array to collect seismic data in the Chukchi Sea from 28 Aug through 10 Sep, and from 20 Oct through 4 Nov.

Barging activities not associated with the seismic exploration also occurred in the Chukchi Sea from mid–Jul through early Oct. Whaling activity occurred south of Pt. Hope near Kivilina during a subsistence hunt for beluga whales in Jul. Three bowhead whales were harvested at Pt. Hope and four bowheads were harvested at Wainwright during the spring subsistence hunt. No bowheads were harvested at these villages during the fall hunt. At Barrow, 13 bowheads were harvested during the spring hunt and seven whales were harvested during the fall hunt.

Beaufort Sea

The *Gilavar* entered the Beaufort Sea to collect seismic data on 12 Sep. Measurements of the underwater sounds produced by the airgun array and the single mitigation airgun were performed on 17–18 Sep in Camden Bay. SOI collected seismic data in the Beaufort Sea from 18 Sep through 3 Oct, 2007.

In addition to deep seismic surveys in the Beaufort Sea, SOI also conducted site clearance and shallow hazards surveys of potential exploratory drilling locations within SOI's lease holdings and along potential pipeline routes as required by MMS regulations. The site clearance surveys were conducted from the *Henry Christoffersen* (*Henry C.*). Exploration equipment on the *Henry C.* included a small airgun array comprised of two 10–in^3 airguns, and several other lower–energy acoustic sources for shallow–penetration, subbottom surveys and for bathymetric mapping. Measurements of the underwater sounds from the airgun array were performed on 30 Aug in Harrison Bay and on 14 Sep near Camden Bay. Site clearance activities were conducted from the *Henry C.* on 23 days from 30 Aug through 3 Oct 2007.

Other industry activity in the Beaufort Sea in 2007 included vessel and helicopter traffic in eastern Harrison Bay in support of oil and gas production by Pioneer Natural Resources, Inc. Vessel and helicopter traffic was also conducted in support of BP Exploration's production activities at Northstar Island. Various other barge activities occurred along the entire Alaskan Beaufort Sea from Barrow to the Canadian border.

Fall subsistence whale hunts were conducted by villagers from Nuiqsut and Kaktovik. Three bowheads were harvested at each village.

Several marine mammal studies not associated with SOI's seismic program were also conducted in the Beaufort Sea in 2007. The MMS conducts the Bowhead Whale Aerial Survey Program (BWASP) annually to monitor fall migration in the Beaufort Sea. The National Marine Mammal Laboratory in partnership with several universities conducted the Bowhead Whale Feeding Ecology Study (BOWFEST) which involved both vessel–base and aerial survey activities in offshore areas near Barrow.

Chapter 3: Chukchi Sea Vessel–Based Monitoring

Environmental conditions in the Chukchi Sea, particularly ice cover, differed greatly between 2006 and 2007, with almost four times as much ice present in 2006 compared to 2007. Ice conditions likely influenced the observed differences in marine mammal distribution and behavior between years and the reduced ice cover in 2007 may have contributed to the generally higher sea conditions and poorer visibility recorded by observers in 2007.

Marine mammal observers collected useable data on more than twice the amount of vessel trackline in the Chukchi Sea during 2006 (29,182 km or 18,133 mi useable effort) compared to 2007 (12,714 or 7,900 mi useable effort). This reflected the large difference in seismic survey activity between the two years with three source vessels operating in 2006 compared to a single source vessel in 2007. The amount of observer effort during 2006 was similar for both seismic (14,780 km or 9,184 mi) and non–seismic periods (14,400 km or 8,948 mi). In 2007, however, monitoring during non–seismic periods (11,904 km or 7,397 mi) far exceeded the effort during seismic periods (810 km or 503 mi), largely due to permitting delays and poor weather during seismic activity. The relatively lower amount of useable seismic effort in 2007 made it difficult to determine the effect of seismic activity on marine mammals by comparing seismic and non–seismic periods using 2007 data alone.

In 2006, marine mammal observers recorded 127 Pacific walrus sightings in the Chukchi Sea compared to 334 walrus sightings in 2007. In 2007, 143 of the walrus sightings were recorded on 24 Aug alone. The Pacific walrus sightings on 24 Aug were recorded before any seismic activity occurred and represented 23% of all useable sightings recorded in the Chukchi Sea over the two years. The walruses observed on 24 Aug may have been in transit from the edge of the pack ice toward the Alaska coast. The retreat of sea ice beyond the shallow waters of the northern Chukchi Sea appeared to cause walruses to use terrestrial haulouts in greater numbers than previously observed. This sighting event suggested that Pacific walruses tend to be patchily distributed and large aggregations swimming in open water may be encountered in years with less ice. Generally, Pacific walrus sighting rates from support vessels far exceeded those from source vessels during seismic periods, however, the opposite was true during non–seismic periods, suggesting localized walrus avoidance of seismic airgun activity. No walrus reaction to the vessel was noted for the majority of walrus sightings during both seismic and non–seismic periods.

Cetaceans were observed from vessels on 79 and 64 occasions in the Chukchi Sea in 2006 and 2007, respectively. The majority of the cetacean sightings were of gray whales (32% and 50% in 2006 and 2007, respectively), and gray whales were observed most often in nearshore areas. Fewer bowhead whales were observed in 2007 compared to 2006, (6 and 25 sightings, respectively). Cetacean sighting rates overall were lower in fall of 2007 compared to 2006. Greater availability of food in the Alaskan Beaufort Sea may have delayed the bowhead migration through the Chukchi Sea in 2007. In both years, cetacean detection rates recorded from both source and support vessels were higher during non–seismic periods than during seismic periods. This suggested that whales may have avoided the seismic activity at distances greater than can be detected by observers on the vessels and is consistent with results from previous seismic surveys in the region. In 2007, the cetacean detection rate from the source vessel during non–seismic periods was much greater than that from support vessels. However, the source vessel had a higher observation platform than most of the support vessels, possibly providing observers with a better vantage.

In 2007, seal detection rates were generally greater from support vessels than source vessels, and the difference was greater during seismic than during non–seismic periods. The same trend of increased detection rates from support vessels during seismic periods was found in 2006, and may suggest that seals reacted to the active airguns by moving away from the source vessel. However, a clear trend indicating avoidance was not found when detection rates within 10 dB increments were examined. A reaction behavior was recorded for ~30% of seal sightings from source vessels during seismic periods and for ~20% of sightings during non–seismic periods, suggesting somewhat greater levels of disturbance during seismic periods. Generally, seal detection rates were lower in 2007 compared to 2006. In 2006, seal detection rates were greater in areas closer to pack ice. The lower overall seal detection rate in 2007 may be due, in part, to decreased ice cover in 2007 in areas where vessels were operating. Based on data collected aboard vessels in 2006 and 2007, no physical injury to marine mammals was observed, and estimates of the number of marine mammals exposed to seismic sounds above behavioral (≥160 dB rms) and safety (≥180 or ≥190 dB rms) thresholds were low relative to population sizes.

Chapter 4: Chukchi Sea Aerial Survey Program

Aerial surveys of marine mammals were conducted in nearshore areas of the Chukchi Sea during the open–water seasons in 2006 and 2007 to gather information on current marine mammal distribution and abundance. The surveys focused on beluga, bowhead, and gray whales, although other marine mammals were recorded when observed.

Beluga whale sighting rates during aerial surveys were greatest during Jul (2006) and Aug (2007). Sightings decreased mid–season and then increased later in the year, which is consistent with earlier studies (Suydam et al. 2001; 2005). In 2006, beluga whale sighting rates and numbers of individuals were highest during the early season in coastal areas (within 5 km of shore). Beluga whale sighting rates were lowest in Aug and steadily increased through Nov with most whales recorded farther offshore during the mid– and late seasons. In 2007, sighting rates were lowest in Sep, perhaps due to lower ice cover.

Bowhead whales were most common during aerial surveys in nearshore areas of the northern Chukchi Sea during Oct–Nov. Small numbers of bowheads were estimated to be in nearshore areas during Jul and Sep 2006 but not in Jul or Sep 2007. Bowheads were not seen during August of either year, but few surveys were conducted during Aug 2006. The relatively higher numbers of bowhead observations during the latter part of the season likely resulted from the movement of bowhead whales through the Chukchi Sea during fall migration. In 2006, bowhead whales were observed during aerial surveys in the Chukchi Sea every month except Aug. Whether bowhead whales observed during Jul 2006 remained in the Chukchi Sea for the entire summer is uncertain given the paucity of aerial surveys during Aug. In 2007, no bowhead whale sightings were reported before Oct when whales would have been returning to the Chukchi Sea from the Beaufort Sea.

Gray whale was the most consistently sighted cetacean species in both 2006 and 2007; however, their distribution and abundance was different in the two years. Based on aerial surveys, gray whales were 2.3 and 4.6 times more abundant in nearshore areas during Jul and Aug of 2007, respectively, than the same months in 2006. In 2006 gray whales were most abundant in Jul and declined during Aug and Sep; whereas in 2007, their numbers peaked in Aug and then declined in Sep. Gray whale distribution within the nearshore area also was different between 2006 and 2007. In 2007, bowheads were most abundant in the northern part of the survey area from about Wainwright to Barrow. In 2006, they were most abundant in the central part of the survey area near Point Lay. Sighting rates were significantly higher close inshore in 2006 and farther offshore in 2007; this was most likely due to differences in prey distribution between years. Gray whale sighting rates in summer during our 2006–07 study were similar to those reported in 1982–86 (Moore et al. 2000); however, sighting rates in autumn in the current study were lower than in the earlier study

The distribution of Pacific walruses in 2007 was much different than in 2006. During 2006, peak sighting rates for walruses were in Jul when they were closely associated with pack ice in nearshore areas. Sighting rates in the nearshore survey area declined substantially during Aug and Sep 2006 as the pack ice retreated offshore. In contrast, 2007 was an exceptionally ice–free year and the pack ice retreated far north early in the season. Ice floes were not available as a haulout platform for walruses during the survey period in 2007. Walruses appeared to have abandoned the pack ice by late August and used terrestrial haul–out sites along the Chukchi Sea coast in Aug and Sep. In Jul 2007, when some pack ice still remained in offshore areas, walrus sighting rates in nearshore areas were lower than during Aug–Nov. The observed level of walrus haulout activity has not been previously documented along the eastern Chukchi Sea coast, although large numbers have been observed at terrestrial haulouts along the Chukotsk coast in earlier years (Belikov et al. 1996).

Chapter 5: Chukchi Sea Acoustic Study Program

In 2007 JASCO Research Ltd carried out an acoustic monitoring study for Shell Offshore Inc (SOI) in the Chukchi Sea along the Alaskan coast using an array of seabed-deployed autonomous acoustic recorders. This study was similar to the net-array program performed in 2006 by Bioacoustics Research Program (BRP) at the Cornell Laboratory of Ornithology (Clark 2007). Both the 2006 and 2007 studies were designed to address the scarcity of data concerning natural and anthropogenic (man-made) underwater sound levels in the Chukchi Sea. The goal was to provide information about migration routes and distributions of marine mammals within the study area during the open-water season as well as characterize ambient and anthropogenic sounds during that time. The acquired acoustic data were processed to identify and classify marine mammal vocalizations, and to determine relative spatial distributions of vocalizing animals as a function of time. Recorded data also quantified sound levels over large distances from seismic airgun pulses produced during the seismic survey.

Thirty recording locations were determined during consultations with agency and stakeholder scientists, SOI, and its consultants. The agreed-upon deployment plan consisted of between five and seven recorders in each of four sub-arrays starting 5 n.mi. from shore and extending from 50 to 170 n.mi. offshore of the Alaskan Chukchi coast at Cape Lisburne, Point Lay, Wainwright and Barrow. Initial deployments of the Ocean Bottom Hydrophone (OBH) recorders were made at 28 of the 30 planned locations from 17 to 20 Jul, 2007. The OBHs operated continuously for up to 56 days from their respective deployment dates. A second deployment of all OBHs was planned for early Sep, but problems with internal floats on the deployed systems slowed the retrieval process and only ten of the systems were retrieved and redeployed on time at the Barrow and Wainwright sub-arrays between 26 Aug and 14 Sep. The original OBHs on the Point Lay and Cape Lisburne lines were left in place but stopped recording 12-16 Sep 2007 after reaching storage capacity. The second deployment of ten OBHs at Wainwright and Barrow recorded continuously until they were retrieved 19-26 Oct 2007. A third originally unplanned deployment of 5 over-winter OBHs set for extended duration recording with a duty cycle of 48 minutes on and 192 minutes off was conducted in late Oct. On this duty cycle the OBHs were expected to record for 270 days (until late Jul 2008). A total of 5 Terabytes of acoustic data were collected during the first two deployments in 2007, representing cumulatively 5 years of continuous sound recording. Automated algorithms were developed and implemented to process these data on a high-speed dedicated computer system. The algorithms included detection routines for vessels, seismic survey noise, and marine mammal vocalizations. Other routines were developed to automatically compute ambient sound levels and root-mean-square (rms) sound levels of seismic survey airgun pulses. All of these analysis routines relied on spectral processing methods that were computationally intensive.

The output of the automated data analysis system included the detection times of each type of non-ambient event (biological sound, seismic pulse or vessel tones) and the ambient level in each 1/2 hour of recording. For biological sounds the classifier determined if the sound was a vocalization from a beluga whale (*Delphinapterus leucas*), bowhead whale (*Balaena mysticetus*), or walrus (*Odobenus rosmarus*). The automated mammal classification routines in some cases incurred unacceptable rates of false classification when the vocalizations had similar frequency content and time duration. Several iterations of revisions to these classification routines, including requirements for more than one type of call to be present to identify as a certain species, were made to optimize performance. Satisfactory performance was achieved; however advancements to these classification systems are ongoing. For seismic pulse sounds the seismic detector computed the rms sound level and the single pulse sound exposure level (SEL). For vessel detections the algorithm returned the number of frequency tones above a preset threshold and the sound pressure level of each. Post processing of these outputs was carried out to generate the displays in several formats that are presented and discussed in this report.

Large numbers of detections of several species of marine mammals were identified on all OBHs. Relatively fewer beluga whales were detected compared to other species. Belugas were detected at all distances offshore at Barrow and Wainwright, though more detections were made inshore at Barrow and offshore at Wainwright. The detection rate at Barrow appeared to trend toward the offshore starting in late Jul, and detections continued throughout Aug. No Beluga detections were made at Cape Lisburne or Point Lay.

The bowhead detector produced several false classifications when certain other species were present. This was, in part, due to the lack of uniquely-identifying features within bowhead calls; walruses in particular had grunts that were very similar to the bowhead “ou ou” sound. However, the detector results were reviewed manually to validate enough detections to draw some conclusions about bowhead locations in summer. Specifically, bowhead vocalizations were detected in the Chukchi Sea starting in late Jul and lasting throughout Aug. There has been some discussion in the literature surrounding observations of bowheads in the Chukchi Sea during the summer period when most bowheads are expected to be in the Canadian Beaufort Sea. These acoustic data add evidence supporting the presence of some bowhead whales in the Chukchi Sea in Jul and Aug. Another of the objectives of this study was to map the 2007 distributions of bowhead calls as they migrate west into the Chukchi Sea in Sep and Oct. Further validation and improvement of the bowhead detection classifier to eliminate false detections caused by walrus vocalizations is necessary before reliable estimates of the relative distribution of bowhead vocalizations can be made.

Walruses were detected at all distances from shore, but there were trends in the offshore distribution that were likely influenced by ice location. Large numbers of walrus calls were detected between 10 Aug and 8 Sep at B50, 50 miles offshore Barrow. The call rate at each OBH in the Barrow line decreased rapidly moving inshore. There were almost no walrus calls before and after this time period on the Barrow OBHs. Wainwright also found large numbers at W40, the 40 mile OBH, though detections started on 30 Jul and continued through 12 Sep. There were two or three brief but strong waves of movement toward shore and back out. These appeared to occur on 9 Aug (out-to-in), 15 Aug (in-to-out), 25 Aug (out-to-in), and 28 Aug (in-to-out). Walrus detections at Cape Lisburne started later, approximately 21 Aug and ended later, about 14 Sep. Nearly all detections were made on PL05 located 5 n.mi. offshore, with numbers decreasing rapidly at OBHs farther offshore. Only a few detections were made just 15 miles offshore of Point Lay. The Point Lay detection period started approximately 14 Aug and continued to 14 Sep.

An additional component of this study was performed after the initial release of results due to an increased interest in the possibility of detecting seal vocalizations in the acoustic recordings. A literature review was carried out to determine the nature of calls that could be expected from the seals, followed by a manual analysis of the data to search for seal vocalizations that could later be used as a basis for developing automated detection criteria. The analysis led to the identification of a certain number of calls from various species of seals, but the conclusion was that seals would only have vocalized infrequently during the summer-fall period of OBH deployment. The collection of identified calls from this study, even combined with other published references, would be insufficient as a basis for setting up an automatic classifier for these species.

Chapter 6: Beaufort Sea Vessel–Based Monitoring Program

Environmental conditions and activity levels varied greatly in the Alaskan Beaufort Sea between 2006 and 2007. Between early Jul and mid– Nov the average area covered by ice was ~1.8 times greater in 2006. As a result, the *Henry Christofferson* (*Henry C.*) was able to collect only 73 km (45 mi) of data using its small airgun array during shallow hazards surveys in 2006, and deep seismic surveys were not attempted. In 2007, deep seismic survey activities were conducted from the *Gilavar* and shallow hazards surveys from the *Henry C.* in the Beaufort Sea. Although reduced ice cover allowed seismic surveys to take place, shallow hazards surveys were limited due to rough sea conditions, possibly related to the lack of sea ice. The poor weather conditions in 2007 meant little useable effort was collected during seismic periods from the source vessels.

During periods of useable effort, an estimated 340 individual marine mammals were reported in 315 groups by MMOs in 2006, and 485 marine mammals were recorded in 363 groups in 2007. Eight marine mammal species were identified, including bowhead whale, gray whale, minke whale, bearded seal, ringed seal, spotted seal, Pacific walrus, and polar bear. Overall, seals were the most commonly sighted marine mammal, followed by cetaceans, polar bears, and Pacific walruses.

There were few cetacean sightings in the Beaufort Sea in 2006, all recorded from support vessels. In contrast, 70 whales were sighted in 32 groups during periods in 2007. Cetacean detection rates during non–seismic periods were similar between source and support vessels in 2007. The low amount of useable seismic effort from the source and support vessels in 2006–07 did not allow meaningful comparison of cetacean detection rates during seismic and non–seismic periods.

Similar numbers of seals were sighted in 2006 (332 seals in 309 groups) and 2007 (392 seals in 318 groups) from the source and support vessels. Seal detection rates in 2006 were highest Sep–Oct, while in 2007 they were highest Jul–Aug. Some of these differences may have been related to differences in ice conditions between the years. Seal detection rates from support vessels were over twice as high during non–seismic periods compared to seismic periods in 2007, but the sample size from seismic period was low.

Pacific walruses are uncommon in the Beaufort Sea and few were observed in 2006–07. All five useable Pacific walrus sightings were recorded in Sep–Oct 2007. There were three sightings of four polar bears in 2006, compared to eight sightings of 14 bears in 2007 in the Beaufort Sea.

Chapter 7: Beaufort Sea Aerial Survey Program

Aerial marine mammal monitoring programs in the Alaskan Beaufort Sea were performed in the fall of 2006 and 2007 in support of seismic exploration activities. Surveys were flown from late Aug through early Oct in 2007 and from late Aug through late Sep in 2006. The goals of the aerial survey program were

- to obtain detailed data on the occurrence, distribution, and movements of marine mammals, particularly bowhead whales; and
- to monitor the ≥120 dB re 1 ɥPa (rms) radius for bowhead cow/calf pairs. If four or more cow–calf pairs were sighted within the ≥120 dB rms zone during an aerial survey, the IHA required that seismic operations shut down until fewer than four cow/calf pairs were recorded in the ≥120 dB rms zone on subsequent surveys.

Though bowhead sighting rates were higher in 2006 and 2007 than in earlier studies, the timing of peak abundance was similar among years and consistent with migration patterns observed during previous studies. Trends in predominant activities and offshore distribution, however, were not similar to results from some previous research. Feeding was much more common than expected in 2007 and this may have been related to the relatively low ice cover. Bowhead sighting rates in the central Alaskan Beaufort Sea remained high throughout early to mid–Sep 2007, with no significant evidence of migratory headings, and a high proportion of the whales moving slowly or apparently engaged in feeding. This contrasted with the more typical behaviors observed in 2006, including significant evidence of migratory headings and the majority of observed activity consisting of traveling at a moderate pace.

Patterns in offshore distribution of bowhead whales in 2007 did not suggest a large offshore deflection of bowhead whales related to vessel or seismic activities. Sighting rates in the region surrounding the seismic survey area were highest at the same distance offshore as the seismic survey itself regardless of seismic activity. Sighting rates west of the seismic survey area were highest in waters closer to shore than the survey area. However, during periods seismic survey activity bowheads were, on average, located at a slightly greater distance from the center of the Sivulliq prospect than during non–seismic periods although this difference was not statistically significant. These results suggest that any deflection of whales around the seismic survey area was small and did not persist far to the west of operations. These trends support previous research indicating bowheads may be more tolerant of seismic operations when food resources are present in the area.

Chapter 8: Beaufort Sea Acoustics Study Program

Passive acoustics with directional autonomous recorders were used to provide information on bowhead migration paths along the Alaskan Beaufort Sea coast, particularly with respect to sound–producing industrial operations. Thirty–five Directional Autonomous Seafloor Acoustic Recorders (DASARs) were deployed in five groups ("sites") of seven recorders, spread over a distance of ~280 km (174 mi) offshore of Alaska's North Slope. At each site the seven–DASAR array was ~5 km (3 mi) wide by 21 km (13 mi) long. The easternmost site (site 5) was north of the village of Kaktovik, and the westernmost site (site 1) was north of Harrison Bay. Sites 3 and 4 were located near SOI's seismic survey area near Camden Bay. The DASARs recorded from ~20 August to 12 October 2007, providing a continuous record of ambient sounds, whale calls, and anthropogenic sounds. Over 540,000 individual bowhead whale calls were identified on all recorders combined representing over 168,000 individual calls that were identified and classified. Call detection rates were highest at the easternmost site and decreased to the west. The highest hourly call detection rate was 462 calls per hour at site 5 on 13 Sep. Call locations tended to be nearer to shore at site 5 and progressively further offshore moving west across the DASAR array sites.

Call location rates (i.e., call detection rates for calls with a location estimate) were compared before, during, and after seismic activities by Shell at sites near (sites 3 & 4) and far away (sites 2 & 5) from the seismic operation. The analysis showed that call location rates dropped significantly at the near sites at the onset of seismic activities, but not at the far away sites. This decrease during seismic periods could have been caused by a reduction in whale calling rate, by avoidance of the area by some whales, or a combination of the two factors. Increases in call detection rates during breaks in seismic activities suggested that some whales remained in the area during seismic periods but changed their calling behavior. Bowheads were observed feeding during aerial surveys and bowhead sighting rates were relatively high near the seismic surveys. Other research has suggested that bowheads are more tolerant of seismic noise when an attractant such as food is present.

Received sound levels resulting from seismic survey activity were compared for whale call locations at DASAR sites 2 and 5 (sites far from the survey activity) with received levels at sites 3 and 4 (sites close to the survey activity). Mean received levels at sites 2 and 5 were estimated at ~100 dB re 1 μPa. Less than 3% of the call locations had received levels that exceeded 120 dB, and less than 1% were exposed to levels exceeding 140 dB. Mean received levels at sites 3 and 4 were ~115 dB re 1 μPa with ~30% exceeding 120 dB and 3–5% exceeding 140 dB using the "concurrent" analysis method (i.e., each whale call was matched to the position and operational state of the airgun array at the closest point in time). Based on full array method (i.e., every received pulse was assumed to have come from the full array), mean received levels were ~130–140 dB with as much as 90% of the received levels exceeding 120 dB and 20–45% exceeding 140 dB. The number of call locations with calculated received sound levels of 185–190 dB re 1 μPa was zero using the concurrent method and one using the full array method. These results suggest that the mitigation measures implemented were effective in preventing calling bowhead whales from being subjected to received levels > 180 dB.

Based on quantile regression, site 2 displayed the greatest north–south spread of bowhead call distributions and calls were generally farther offshore later in the year, as was the case at sites 3 and 4. At site 4 the call distribution experienced two non–parallel oscillations, i.e., alternating periods of spreading out and tightening of the call locations. The call distribution at site 5 showed regular onshore-offshore oscillations with a period of approximately 20 days.

Certain parts of the call distributions at some sites changed while seismic operations were ongoing. At site 2, the offshore distance of the lower ~1/3 of the call distribution increased by ~130 m for every 1 dB increase in received sound level from airgun pulses. At site 3 the lower 2/3rd of the call distribution was closer to shore by ~250 m for every 1 dB increase in received sound level. The number of calls at site 3 was low and the change in distribution could have resulted from a southern deflection away from seismic activities or the southernmost whales calling at a higher rate than whales close to the seismic survey. At site 4 the upper 1/3rd of the distribution was ~300 m farther offshore for every 1 dB increase in received level. This could have resulted from a northward deflection away from seismic activity or cessation of calling by whales approaching the survey area. At site 5 no significant relationship between offshore position of call locations and seismic survey activity was apparent.

Chapter 9: Other Industry Studies

In addition to the studies conducted by SOI and described in the earlier chapters of this report other industry–sponsored studies were conducted by several companies in support of development activities in offshore areas of the Beaufort Sea during the open–water period 2007. These studies included an underwater acoustic program to monitor the fall bowhead whale migration past Northstar Island by BP Exploration (Alaska) Inc. (BPXA); and acoustic program and aerial surveys in eastern Harrison Bay in support of activities at Oooguruk Drilling Island (ODS) by Pioneer Natural Resources, Alaska, Inc. (Pioneer); a vessel–based marine mammal monitoring program during barge activities between West Dock and Cape Simpson by FEX LP; and the Bowhead Whale Feeding Ecology Study (BOWFEST) by the National Marine Mammal Laboratory (NMML) in partnership with various universities.

BPXA—Northstar

During the bowhead whale migration in Sep 2007, Greeneridge Sciences (on behalf of BP) implemented an acoustic monitoring program north–northeast of BP's Northstar oil development. Monitoring objectives in 2007 were identical to those in 2005 and 2006, but modified relative to those in earlier years. The 2007 monitoring program was designed to detect significant changes in sounds produced by Northstar or in the number of whales (as indicated by their calls) migrating along the southern part of the bowhead migration corridor.

On 28 Aug 2007, five DASARs were deployed at locations 11.4–21.4 km (6.2–11.6 nmi or 7.1–13.3 mi) NNE of Northstar Island. These instruments recorded sounds continuously in the 10–450 Hz frequency band for ~36 days, until 3 Oct 2007. Simultaneously, near–island recordings were obtained from two DASARs placed 410 and 480 m (1345 and 1575 ft) from Northstar over the same period. Vessel traffic to and from Northstar by ACS boats increased in 2007 compared to 2004–2006, but overall vessel traffic was still below 2001–2003 values. Median broadband levels as recorded by the near–island recorders were higher than all previous years except 2005. Wind speeds were unusually high in 2007, which contributed to higher ambient sound levels. Overall, industrial sounds from Northstar in 2007 were about the same as in 2004–2006, except for the increased frequency of transient high–level sounds associated with boats.

In total, 11,780 bowhead whale calls were recorded in ~36 days at DASAR locations EB (2 recorders), CC, and CA. A total of 10,146 calls, or 282 calls/day, were detected by DASARs EB and CC combined. This compared to 110 calls/day in 2001, 208 calls/day in 2002, 895 calls/day in 2003, 1182 calls/day in 2004, 35 calls/day in 2005, and 38 calls/day in 2006, based on data from the same two sites each year. The maximum call detection rate in 2007 was 228 calls per hour. A comparison of bearings from DASAR EB in 2001–2007 showed that the 2007 bearing directions were distributed similarly to previous low–ice years such as 2002, 2003, and 2004. The much higher call counts in 2007 compared to the two previous years were probably related to the absence of nearshore pack ice during the 2007 season.

Pioneer—Oooguruk Drillsite

Pioneer conducted an acoustic program and an aerial survey program in support of construction activities associated with on offshore drilling island (ODS) in eastern Harrison Bay in 2007. These programs were both continuations of studies begun in 2006.

For the acoustics program, bottom–founded hydrophones (OBH) were used to characterize underwater ambient sound levels, and sounds from construction activities and vessels used in support of operation at ODS. Measurements of underwater sound resulting from construction activities on ODS were recorded on 19 through 23 Sep 2007 at two locations 6.4 and 14.5 km (4 and 9 mi) north of ODS. No sounds that could be attributable to activities on ODS or vessel traffic in support of ODS were audible above ambient noise in the recordings from either OBH. Ambient sound levels were essentially identical at both stations in 2007 and ranged from 105.9 to 109.9 dB (rms). Nine periods of marine mammal vocalizations were identified, three of which were attributed to bowhead whales. The remaining six vocalizations were thought to be ringed or bearded seals.

The aerial survey program was designed to assess the presence and distribution of bowhead whales and other marine mammals within 24–32 km (15–20 mi) of ODS. Eight surveys were flown from 14 Sep through 4 Oct 2007 with a Bell 412 helicopter. The amount of useable data was limited due to poor sighting conditions resulting in only 28.7% of the effort categorized as useable. Only one marine mammal (a seal) was observed during useable periods of effort. Sightings during unuseable effort included a group of 10 seals and one polar bear. In addition, 4 bowhead whales were observed north of the survey area while transiting between transect lines.

FEX LP Barging

FEX conducted barging activities between West Dock and Cape Simpson in support of oil and gas exploration in the National Petroleum Reserve–Alaska. During 31 Jul through 24 Aug 10 round–trips were made by barges and marine mammal observers (MMOs) onboard the barges searched for and recorded observations of marine mammals from the bridge or catwalk. In total, 901 seals were recorded by MMOs, most of which (~76%) were ringed seals. Approximately 18% of the seals could not be identified to species. Spotted seals comprised ~5 % and bearded seals < 1% of the seal total. MMO's identified 38 bowhead whales, 10 gray whales, and two humpback whales during the barge activities. The species of one additional whale was not determined. All whale sightings were recorded in Smith Bay. All bowhead sightings occurred from 15 through 18 Aug.

Bowhead Whale Feeding Ecology Study (BOWFEST)

The National Marine Mammal Lab (NMML) and NOAA Fisheries in partnership with various universities began a study of bowhead whale feeding ecology (BOWFEST) in 2007. The study focused on late summer oceanography and prey densities relative to whale distribution over continental shelf waters within 100 miles north and east of Point Barrow. Offshore study components included aerial surveys, an acoustic program, oceanographic sampling, a bowhead tagging program, bowhead harvest monitoring and tissue sampling.

Aerial surveys were conducted with a Twin Otter fixed–wing aircraft from 22 Aug through 11 Sep 2007. All bowhead sightings (16 sightings of 49 individual) were recorded on 23 and 24 Aug. Other marine mammal sightings included beluga and gray whales, ringed and bearded seals, Pacific walrus, and polar bear. Within the study period, 147 pictures (183 bowhead whale images) for photogrammetry and 147 pictures (165 whale images) for photo identification were taken.

Six hydrophone packages were deployed offshore north and east of Barrow. Most of the instruments remained deployed through the winter and recovery was scheduled after the 2008 breakup. No calls that could be attributed to bowhead whales were found during preliminary analyses from one hydrophone which operated offshore of Cape Halkett from 16 Aug to 11 Sep.

Most results from the oceanographic sampling and bowhead harvest monitoring and tissue sampling are preliminary or not yet available. A few whales were sighted during the tagging program but could not be relocated and no bowhead tagging was accomplished in 2007.

Chapter 10: Discussion, Conclusions and Potential Effects of Seismic Activities on Marine Mammals in the Chukchi and Beaufort Seas

Data on the distribution and abundance of marine mammals was collected during offshore seismic exploration activities in the Chukchi and Beaufort seas in 2006 and 2007. Vessel-based data were collected by marine mammal observers onboard seismic and support vessels, and aerial survey data were collected in the Beaufort Sea as part of the monitoring and mitigation program. In addition aerial surveys were conducted in the nearshore areas of the Chukchi Sea and a passive acoustic monitoring program was conducted in both the Chukchi and Beaufort seas. The results of these individual monitoring or research programs are discussed in the various chapters of this report. The discussion and conclusions presented in this chapter should be viewed in the framework of this limited data set, which encompasses only two years of data collected across a large area in years with markedly different ice–cover conditions.

Gray whale was the most frequently reported cetacean species in the Chukchi Sea in both 2006 and 2007. Other cetacean species reported regularly included bowhead and beluga whales. Differences in cetacean detection rates and seasonal peaks between years may have been related to differences in ice and weather conditions. Ice cover was reduced in 2007 compared to 2006 and higher sea conditions in 2007 resulted in poor visibility in 2007 compared to 2006.

Bowhead whale calls were recorded in the Chukchi Sea by underwater hydrophones during the fall in 2006 and during summer and fall in 2007. Visual observations of bowheads were made during summer 2006, but in 2007 no bowheads were visually observed before Oct during the seismic monitoring program in the Chukchi Sea. A Japanese research vessel however reported a sighting of about 30 bowhead whales in the Chukchi Sea on 9 Aug 2007. These observations and recording suggest that at least some bowhead whales may summer in the Chukchi Sea.

The most dramatic difference in marine mammal distribution and abundance between years resulted from the presence of large number of Pacific walrus at land haulouts in 2007. In 2006 walrus sightings were reported primarily in offshore open–water habitats. In 2007 the pack ice retreated north of the Chukchi Sea into deeper waters of the Arctic Ocean and was not available as a resting platform near shallow feeding habitat in the Chukchi Sea forcing walrus to use haulouts on land. The extensive use of land haulouts by walrus in the eastern Chukchi Sea had not been previously reported.

Five polar bear sighting were reported from vessels operating near pack ice in 2006. No polar bears were reported from vessels in 2007 or during aerial surveys in the Chukchi Sea in 2006 or 2007.

Deep seismic exploration planned for the Beaufort Sea in 2006 was not conducted due the extensive ice conditions, and exploratory activities in 2006 were confined to shallow hazards surveys. Deep seismic surveys as well as shallow hazards surveys were performed in 2007. A marine mammal monitoring program similar to that in the Chukchi Sea was conducted in the Beaufort Sea with additional monitoring during aerial surveys as required under conditions in the IHA. In a separate research program an acoustic net array of underwater recorders provided information on the levels of industrial and ambient sound and on the locations of calling bowhead whales.

Few cetaceans were sighted during vessel operations in the Beaufort Sea in 2006 compared to 2007 due to reduced effort in 2006. In contrast, cetaceans (primarily bowhead whales) were commonly observed during fall aerial surveys in both 2006 and 2007. Calling bowhead whales were also monitored with underwater recorders during fall migration in the vicinity of BP's Northstar oil development. Pacific walrus are uncommon in the Beaufort Sea and only five walrus sightings were recorded in 2007; no walrus sightings were recorded in 2006. Polar bears were sighted more frequently in 2007 than 2006 during both vessel–based and aerial monitoring. Most polar bear sighting were associated with the barrier islands.

From 29 Aug to 10 Sep, sounds associated with seismic surveying in the Chukchi Sea were recorded on bottom–founded acoustic recorders deployed near Point Lay, Wainwright, and Cape Lisburne. During that time the SPLs for all stations except PLN40, which was well offshore and nearest the seismic survey activity, were generally below 115 dB re 1µPa (rms). Over a 32 minute sampling period, average SPLs at PL40 during the seismic survey ranged from 100 to 137.4 dB re 1µPa (rms) with individual peaks reaching 142 dB re 1µPa, and on two occasions exceeding 144 dB re 1µPa (rms). In the Beaufort Sea some of the underwater recorders were located near the seismic survey activities and received levels were as high as 153 dB re 1µPa (although actual levels may have been greater since the recorders overloaded at this level). Received levels at recorders farther away from the seismic survey activity were lower ranging from ~78 to 126 dB re 1µPa at site 2 located ~113 km west of the seismic activity, and ~82 to 126 dB re 1µPa at site 5 located ~109 km east of the seismic activity.

The effect of this range of sound exposure on marine mammals is unknown. In some cases comparisons of sighting rates during seismic and non-seismic periods suggested localized avoidance of seismic activities by seals. Sighting rates of cetaceans were usually greater during non-seismic periods also suggesting avoidance of underwater seismic sound. Data from aerial surveys in the Beaufort Sea in 2007 however indicated that bowhead whales did not appear to avoid the area near active seismic surveys.

These whales were primarily engaged in feeding activity and the results of the 2007 aerial survey are in agreement with previous research indicating that feeding bowheads are less likely to avoid seismic exploration activities than whales engaged in other activities such as migration.

Impacts to marine mammal individuals and populations would potentially increase with expanded exploration and development of oil and gas in the Beaufort and Chukchi seas. Based on the results of a recent sale (6 Feb 2008) of offshore leases, there is clearly interest in further exploration and possible development of oil and gas prospects in the Chukchi Sea. At this time it is not possible to predict how many new developments might occur from future exploration activities. However, it is likely that at least some current prospects would be developed or at least explored to a greater extent in the near future. As additional exploration and development occurs the potential for impacts caused by industrial sounds in the marine environment will rise as will the potential for vessel strikes of marine mammals due to increased ship traffic in the area. Without proper mitigation such impacts could affect marine mammal individuals and result in a decrease in the availability of marine mammals for subsistence use by villages along the coast of Alaska. It appears unlikely that populations of marine mammals would be affected at current levels of exploration although it remains unclear how other types of impacts like changes in temperature across the Arctic may ultimately affect these populations and their ability to adapt to additional human influence in their habitats.

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1. INTRODUCTION AND REPORT OBJECTIVES[1]

This report presents a comprehensive overview of the results of the marine mammal monitoring and mitigation program, and the research programs conducted by Shell Offshore Inc. (SOI) in partnership with ConocoPhillips Alaska Inc. (CPAI) in the Chukchi Sea during seismic activities in 2007, as well as SOI's seismic and other offshore activities in the Beaufort Sea. Mitigation and monitoring during seismic exploration activities occurred in a relatively small portion of the MMS Chukchi Sea Lease Sale Area 193 and in the vicinity of specific lease holdings in the Beaufort Sea. Research programs were conducted across large areas of the Beaufort and Chukchi seas. Vessel–based monitoring and mitigation programs in the Chukchi and Beaufort seas are discussed in Chapters 3 and 6, respectively, and aerial–based monitoring and mitigation in the Beaufort Sea is discussed in Chapter 7. The Chukchi Sea research program included an aerial monitoring component over the nearshore waters to ~32 km (20 mi) offshore of the Chukchi Sea coast between Pt. Hope and Barrow (Chapter 4), and an acoustic component using arrays of bottom–founded recorders deployed relatively close to the coast and in areas further offshore (Chapter 5). During the research program in the Beaufort Sea, five arrays of directional recorders were used to monitor marine mammal (primarily bowhead whales) calling behavior relative to seismic activities (Chapter 8). The report describes the methods, results, conclusions and limitations of each of these data sets.

SOI conducted vessel–based seismic exploration in the Chukchi (in partnership with CPAI) and Beaufort seas during the 2007 open–water season. Acquisition of seismic data was accomplished using an industry standard airgun array and hydrophone streamers towed by the source vessel *Gilavar*. In addition to the deep seismic surveys SOI also conducted shallow hazard surveys on existing lease holdings in the Beaufort Sea. Marine mammal monitoring and mitigation around the seismic vessel, sound source modeling, and sound source measurements were conducted prior to and/or during operations. Monitoring and mitigation in the Chukchi and Beaufort seas was accomplished by marine mammal observers (MMOs) onboard seismic and support vessels. Additional monitoring and mitigation in the Beaufort Sea involved the use of aerial surveys to determine presence and locations of bowhead whale cow/calf pairs during seismic activities. The results from these efforts were provided in a 90–day report submitted to the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) after operations were completed (Funk et al. 2008). In addition to monitoring and mitigation associated with the seismic activities, SOI agreed to implement a research program including acoustic and aerial monitoring components in the Chukchi Sea and an acoustic component in the Beaufort Sea during the seismic exploration activities in 2007.

Data from several additional sources were included in the report to supplement the information described above. The National Science Foundation (NSF) and the Minerals Management Service (MMS) conducted bowhead whale feeding studies east of Barrow and the Joint Monitoring Program (JMP) participants (SOI, CPAI, and in 2006 GXT) agreed to perform aerial surveys over the study area offshore of Barrow to supplement the results of the NSF–MMS surveys. Reports on these data will be forthcoming and discussion of this program is included to the extent possible in this report. The MMS also conducts aerial surveys of bowhead whales in the Beaufort Sea on an annual basis. The MMS data for the 2007 surveys are available online at http://www.mms.gov/Alaska/ess/bwasp/2007bwasp/2007bwasp.htm .

To the extent possible, this report integrates the studies conducted as part of the monitoring

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[1] Dale W. Funk, Robert Rodrigues, and Darren S. Ireland, LGL Alaska Research Associates, Inc., Anchorage, Alaska.

program into a broad–based assessment of industry activities and their impacts on marine mammals in the Chukchi and Beaufort seas during 2007. As part of this integration, monitoring and mitigation data collected in 2006 and 2007 were combined to allow a more comprehensive analysis of marine mammal distribution and density in the Chukchi and Beaufort seas. It is noteworthy that differences in the extent of sea ice in 2006 vs. 2007 likely resulted in observable differences in the distribution and behavior of some marine mammal species. Pacific walruses were generally observed swimming in open water offshore or were associated with pack ice in 2006. Similar observations of walruses were also made in 2007, however thousands of walruses were also observed hauled out on land along the Chukchi Sea coast between Pt. Hope and Barrow. In the Beaufort Sea bowhead whales were observed east of Barrow as early as mid-Aug, and observations during aerial surveys suggested a possible increase in bowhead feeding behavior over that observed in previous years in the central and eastern Alaskan Beaufort Sea. Factors likely contributing to differences in Pacific walrus and bowhead whale distribution/activity between 2006 and 2007 are discussed in detail in several chapters of this report.

In addition, other known industry and human activities occurring offshore in the Chukchi and Beaufort seas are summarized (Chapter 2). These other activities included barging and vessel traffic, drilling island construction, oil production operations, and subsistence whaling. Barging activities were conducted by Island Tug and Barge, Bowhead Transportation, Crowley Marine Systems, FEX LLC, Pioneer Natural Resources, Inc., and BP Exploration (Alaska), Inc. Some of these companies conducted their own studies and graciously provided copies of their reports and data for use in describing industry activities and studies.

We included information that was available describing the subsistence whale hunts in the project area. This information was initially provided by the Barrow Communications Center and the Alaska Eskimo Whaling Commission. These data were later updated with information from Suydam et al. (2008).

We further attempted to integrate all of the activities that were occurring in the Beaufort and Chukchi seas during the open–water period of 2007 and assess what, if any, impacts there were on marine mammals inhabiting or migrating through these areas. This report focuses on the potential impacts to marine mammals from underwater sound associated with various industry activities and related vessel traffic during 2007. The report will begin to establish long–term data sets for evaluating changes in the Chukchi and Beaufort sea ecosystems by providing a regional synthesis of available data on industry activities in offshore areas of arctic Alaska that may influence marine mammal density, distribution and behavior.

Objectives and Assumptions

As described above, the primary objective of this report was to provide detailed descriptions of the various studies conducted by SOI and the other JMP participants, which included:

- deployment of arrays of bottom–founded acoustic recorders along the Alaskan Chukchi Sea coast from Pt. Hope to Barrow, Alaska with additional recorders placed further offshore;
- aerial monitoring over the nearshore waters and coastline between Pt. Hope and Barrow;
- deployment of directional autonomous seafloor acoustic recorders model B (DASAR-b) to monitor marine mammal vocalizations (primarily bowhead whales) and industrial sounds in the Beaufort Sea;
- aerial surveys over lease prospects in the Beaufort Sea (primarily near Camden Bay); and

- analysis of a combined data set consisting of all marine mammal sightings from the seismic and support vessels operating in the Chukchi and Beaufort seas in 2006 and 2007.

The objectives of these studies were to:

- provide data to begin to fill current gaps in our understanding of the relative abundance and distribution of marine mammals in the Chukchi and Beaufort seas; and
- assess the potential impacts of seismic activity on marine mammals in the Chukchi and Beaufort seas.

Additionally, other human activities in the Beaufort and Chukchi seas that occurred during the seismic program but were unrelated to work by JMP participants are also described. These activities may have influenced marine mammal responses to the seismic program.

In preparing this report we worked under the following assumptions:

- The report primarily addresses the monitoring studies conducted by the JMP participants and the effects on marine mammals from the 2006 and 2007 seismic programs conducted by SOI (2006 and 2007), CPAI (2006) and GXT (2006).
- Marine mammals are the focus of the report, and the report is not intended to address all aspects of the marine ecosystems of the Chukchi and Beaufort seas.
- The primary potential impacts addressed are those resulting from underwater sound from airguns and the vessels themselves.
- This report is intended to document the current monitoring programs in the Alaskan Arctic and is not intended as a complete retrospective of previous work in these areas.
- Information presented from studies conducted by other companies or organizations is usually available in reports issued by those entities. Those reports should be consulted for more detailed information on these separate studies.

Report Organization

The report describes the various types of industry and other activities in the Chukchi and Beaufort seas during 2007, summarizes the results of industry studies in these areas, and provides an initial analysis of the cumulative effects of human activities on marine mammals in 2007. The report is divided into 10 chapters and appendices.

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2. INDUSTRY AND OTHER HUMAN ACTIVITIES[1]

As part of a continuing exploration program SOI conducted 3D–seismic activities in both the Chukchi and Beaufort seas and shallow hazards and site clearance surveys in the Beaufort Sea in 2007. Other industry activities, monitoring studies, and subsistence harvest activities also occurred in both seas. This chapter describes the various types of human activities during the 2007 open–water period in the Chukchi Sea followed by a description of similar activities in the Beaufort Sea. A regional timeline of activities at the end of this chapter puts the temporal aspects of the 2007 activities in the Chukchi and Beaufort seas in perspective.

Seismic Vessel Component

Marine seismic surveys emit sound energy into the water (Greene and Richardson 1988; Tolstoy et al. 2004a,b), and have the potential to affect marine mammals, given the possible auditory and behavioral response of many such species to underwater sounds (Richardson et al. 1995; Gordon et al. 2004; Nowacek et al., 2007; Southall et al. 2008). The effects could consist of behavioral or distributional changes, and perhaps (for animals close to the sound source) temporary or permanent reduction in hearing sensitivity, although this has not been confirmed in the technical literature. Either behavioral/distributional effects or auditory effects (if they occur) could constitute "taking" under the provisions of the U.S. Marine Mammal Protection Act (MMPA) and the U.S. Endangered Species Act (ESA).

Incidental Harassment Authorization

Seismic survey operations have the potential to "take" marine mammals by harassment. As in 2006, SOI submitted applications to the National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (USFWS) for Incidental Harassment Authorizations (IHAs) that contained specific monitoring and mitigation measures designed to minimize such "take." IHAs issued to seismic operators included provisions to minimize the possibility that marine mammals close to the seismic source might be exposed to levels of sound high enough to cause hearing damage or other injuries. No serious injuries or deaths of marine mammals occurred during seismic operations in the Chukchi Sea in 2006 and none were anticipated from the 2007 seismic surveys, given the nature of the operations and the mitigation measures implemented. As in 2006, no injuries or deaths of marine mammals were attributed to the 2007 seismic activities.

Under current NMFS guidelines (e.g., NMFS 2005; NMFS 2006a,b), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which the received pulse levels are ≥180 dB re 1 μPa (rms)[2] for cetaceans and ≥190 dB re 1 μPa (rms) for pinnipeds. Those safety radii are based on an assumption that seismic pulses at lower received levels will not injure these mammals or impair their hearing abilities, but that higher received levels might have some such effects. The mitigation measures required by IHAs are, in large part, designed to avoid or minimize exposure of cetaceans and pinnipeds to sound levels ≥180 and 190 dB (rms), respectively.

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[1] Robert Rodrigues, Darren S. Ireland, and Dale W. Funk, LGL Alaska Research Associates, Inc.

[2] "rms" means "root mean square," and represents a form of average across the duration of the sound pulse as received by the animal. Received levels of airgun pulses measured on an "rms" basis are generally 10–12 dB lower than those measured on the "zero–to–peak" basis, and 16–18 dB lower than those measured on a "peak–to–peak" basis (Greene 1997; McCauley et al. 1998, 2000). The latter two measures are the ones commonly used by geophysicists. Unless otherwise noted, all airgun pulse levels quoted in this report are rms levels.

Disturbance to marine mammals could occur at distances beyond the safety (power–down) radii if the mammals were exposed to moderately strong pulsed sounds generated by the airguns (Richardson et al. 1995). NMFS assumes that marine mammals exposed to airgun sounds with received levels ≥160 dB re 1 μPa (rms) have the potential to be disturbed behaviorally. That assumption is based mainly on data concerning behavioral responses of baleen whales, as summarized by Richardson et al. (1995) and Gordon et al. (2004). Dolphins and pinnipeds are generally less responsive than baleen whales (e.g., Stone 2003; Gordon et al. 2004), and 170 dB (rms) may be a more appropriate criterion of potential behavioral disturbance for those groups (LGL Ltd. 2005a,b). However, this 170 dB (rms) criterion is not recognized by NMFS. In general, disturbance effects are expected to depend on the species of marine mammal, the activity of the animal at the time of disturbance, the distance from the sound source, the received level of the sound, and the associated water depth. Some individuals may under certain circumstances exhibit behavioral responses at received levels somewhat below the nominal 160 or 170 dB (rms) criteria, but others may tolerate levels somewhat above 160 or 170 dB (rms) without reacting in any substantial manner. Marine mammal behavioral responses to seismic operations have been consistently shown to be temporary and short term (Richardson et al. 1995), and have not appeared to significantly affect marine mammal populations.

In Nov 2006, SOI requested that NMFS issue an IHA to authorize non–lethal "takes" of whales and pinnipeds incidental to the seismic operations in the Chukchi Sea and the mid– and eastern Alaskan Beaufort Sea during the 2007 open–water seismic program (SOI 2006) pursuant to Section 101(a)(5)(D) of the MMPA. The NMFS published notices regarding the proposed issuance of the IHA for the surveys in the Chukchi and Beaufort seas in the *Federal Register* on 7 Jun 2007 and public comments were invited. NMFS issued an IHA to SOI to cover seismic activities in the Chukchi and Beaufort seas with an effective date of 20 Aug 2007 through 1 Aug 2008. The IHA authorized "potential take by harassment" of various cetaceans and pinnipeds during the marine geophysical cruises described in this report.

In Apr 2007 SOI also requested that the USFWS issue an IHA to authorize potential "taking" of walruses and polar bears. The USFWS published a notice regarding the proposed issuance of the IHA on 1 Jun 2007. The USFWS issued the IHA to SOI on 20 Jul with an expiration date of 30 Nov 2007.

The IHAs were granted to SOI with the following assumptions:

- the numbers of marine mammals potentially harassed (as defined by NMFS criteria) during seismic operations would be "small";
- the effects of such harassment on marine mammal populations would be negligible;
- no marine mammals would be seriously injured or killed;
- there would be no unmitigated adverse effects on the availability of marine mammals for subsistence hunting in Alaska; and
- the agreed upon monitoring and mitigation measures would be implemented.

The IHA issued by NMFS for the Chukchi and Beaufort sea seismic surveys authorized harassment "takes" of one ESA–listed species, the bowhead whale (*Balaena mysticetus*), as well as non–listed species including gray whale (*Eschrichtius robustus*), killer whale (*Orcincus orca*), beluga whale (*Delphinapterus leucas*), harbor porpoise (*Phocoena phocoena*), and ringed (*Phoca hispida*), spotted (*Phoca largha*), and bearded (*Erignathus barbatus*) seals.

The polar bear (*Ursus maritimus*) and Pacific walrus (*Odobenus rosmarus*) also occur in the project area. These species are managed by the USFWS, unlike the other arctic marine mammals (which are managed by NMFS). The IHA issued to SOI by USFWS authorized the incidental taking of walruses and polar bears in conjunction with seismic activities in the Chukchi and Beaufort seas and required the applicant to observe a 190 dB (rms) safety radius for these species.

Chukchi Sea

Seismic Operations

SOI collected offshore seismic data in the Chukchi Sea during summer and fall 2007 in support of potential oil and gas exploration and development. Seismic survey data were acquired from the *Gilavar*, a seismic source vessel that towed an airgun array and hydrophone streamers to record reflected seismic data. A number of other support/monitoring vessels also operated in the Chukchi Sea during the 2007 open–water period. Some vessels worked closely with the *Gilavar* in support of seismic activities, while others operated in support of acoustic research activities. Several vessels contracted by SOI also transited the Chukchi Sea in 2007 while enroute to the Beaufort Sea.

Dates of Operations

The *Gilavar* left Dutch Harbor on 18 Jul to travel to the project area, and entered the Chukchi Sea on 21 Jul. Operations were then delayed while SOI waited for final approval of the IHA which was issued on 20 Aug. The sound source radii used for mitigation had been predicted prior to the 2006 field season via acoustic modeling procedures (Austin et al. 2006) which were reported along with empirical measurement of the 2006 sound levels produced by the seismic array in the 90–day report (Patterson et al. 2007). Although the same array used in 2006 was used again in 2007, SOI decided to conduct measurements of the radii in 2007 in the location where the seismic activities were to occur. SOI's seismic contractor deployed the seismic acquisition equipment, and sound source measurements of the airgun array were conducted by JASCO Research Ltd. (JASCO) on 28 and 29 Aug during 9 hr of seismic shooting. JASCO calculated preliminary disturbance and safety radii within 72 hr of completion of the measurements and SOI began collecting seismic data. The methods used to conduct the sound source measurements and the results are discussed in detail in SOI's 2007 90–day report (Funk et al. 2008).

The *Gilavar* collected seismic data in the Chukchi Sea from 28 Aug through 10 Sep and departed the Chukchi Sea on 12 Sep to collect seismic data on specific SOI lease holdings in the Beaufort Sea. The *Gilavar* returned to the Chukchi Sea on 8 Oct to conduct further seismic exploration. The *Gilavar* was not able to conduct seismic acquisition at this time due to possible conflict with whalers at Wainwright and Point Hope and transited the Chukchi Sea to Nome. The *Gilavar* reentered the Chukchi Sea on 15 Oct and collected seismic data from 20 Oct through 5 Nov at which time weather conditions precluded further exploration activities. The *Gilavar* left the Chukchi Sea on 8 Nov and arrived at Dutch Harbor on 11 Nov. SOI completed ~2916.1 km (1812.0 mi) of deep–seismic survey line in the Chukchi Sea in 2007. The analyses of marine mammal data collected during seismic survey activity included periods during which airgun/s were firing during ramp up, lead in, and lead out periods, and totaled ~3931 km (~2443 mi) of trackline in the Chukchi Sea.

Location of Activities

The geographic region where the seismic surveys occurred was located in the Chukchi Sea MMS OCS Planning Area designated as Chukchi Sea Sale 193 (Fig. 2.1). The seismic survey activities were conducted at locations ≥80 km (50 mi) offshore.

Navigation

Throughout the surveys, the source vessel position and speed were logged digitally every ~60 s. In addition, the position of the source vessel, water depth, and information on the airgun array were logged for every airgun shot while the source vessel was collecting geophysical data. The geophysics crew kept an electronic log of events, as did the marine mammal observers (MMOs) while on duty. The MMOs also recorded the number and volume of airguns firing when the source vessels were offline (e.g., prior to shooting at full volume) or were online but not recording data (e.g., during airgun or computer problems).

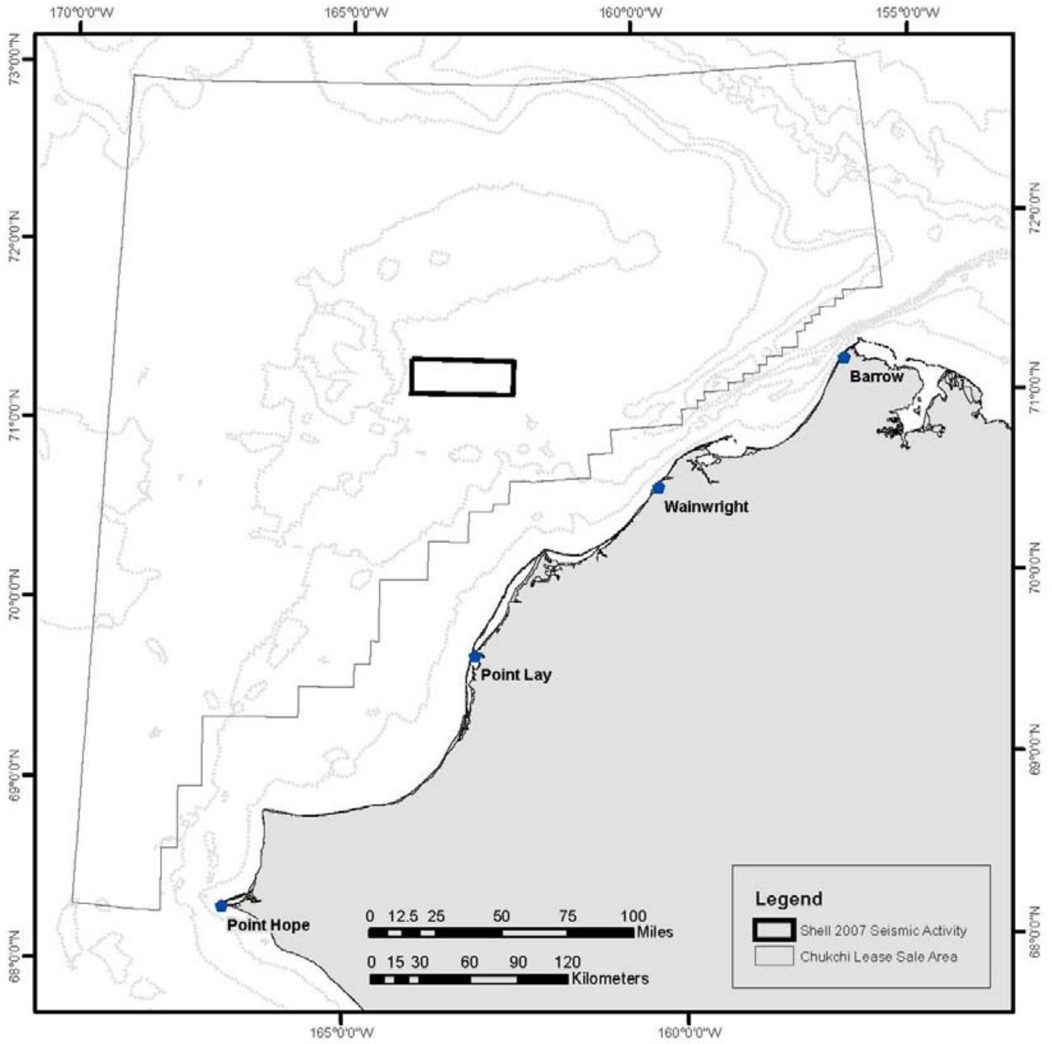


FIGURE 2.1. Location of the MMS Chukchi Sea Lease Sale 193 Planning Area within which SOI conducted seismic surveys in 2007.

Airgun Description

SOI used two of WesternGeco's 3147 in^3 three–string arrays of Bolt airguns which were towed ~276 m behind the *Gilavar* and fired alternately to collect 3–D seismic survey data in the Chukchi Sea. Each array was composed of three identically–tuned Bolt airgun sub–arrays, each with eight airguns and a total volume of 1049 in^3, operated at an air pressure of 2000 psi. Each string was 15 m (49 ft) in length, and was 8 m (26 ft) from the adjacent string(s). The individual airguns ranged in volume from 30 to 235 in^3, and each string included two 235–in^3 and two 125–in^3 airguns in two–gun clusters. The airgun arrays were towed at a depth of 6 m (19.7 ft). The system also included four to six hydrophone streamers 4200 m (2.6 mi) in length and spaced 100 m (328 ft) apart which recorded reflected sound energy. Air compressors aboard the *Gilavar* were the source of high pressure air used to operate the airgun arrays. Seismic pulses were emitted at intervals of 25 m (~11 sec) while the *Gilavar* traveled at a speed of 4 to 5 knots (7.4–9.3 km/h). In general, the *Gilavar* towed this system along a predetermined survey track, although adjustments were occasionally made during the field season to avoid obstacles or during repairs to the equipment. The airgun array is described in more detail in SOI's 90–day report for its 2007 seismic activities (Funk et al. 2008).

Barging and Other Vessels

In addition to the vessel traffic associated with the seismic activities, other vessel traffic also occurred in the Chukchi Sea during the 2007 open–water season (Table 2.1). This vessel traffic was in support of other industry activity not associated with the current seismic surveys, and with barge activity in support of villages. In addition to the vessel traffic in Table 2.1, Crowley Marine Services operated three tugs with barges between Point Hope and Barrow from early Aug through mid–Sep.

TABLE 2.1. General Chukchi Sea vessel traffic for operations not specifically associated with seismic exploration activities in the Chukchi Sea in 2007.

Vessel	Type	Period	Location
Lois H/Klinkwan	Tug and barge	Mid-July to early Aug.	1 R/T transit of Chukchi Sea
Greta Akpik	Landing craft	Late July	Transit Chukchi Sea to Barrow
Greta Akpik	Landing craft	Late Aug. to early Sept.	Transit Chukchi Sea from Barrow
Nunaniq	Landing craft	Early Aug.	Transit Chukchi Sea to Barrow
Nunaniq	Landing craft	Late Aug. to early Sept.	Transit Chukchi Sea from Barrow
Island Monarch/ Island Trader	Tug and barge	Early Aug. to early Oct.	2 R/T transits of Chukchi Sea

Whaling Activities

Subsistence hunting for bowhead whales occurred in the Chukchi Sea during both the spring and fall seasons in 2007 (Suydam et al. 2008). Three bowheads were landed by villagers from Point Hope and six whales were struck and lost during the spring season from 15 Apr through 17 May. Four bowheads were harvested by villagers at Wainwright with one whale struck and lost during the spring season from 5 through 29 May. No bowhead whales were landed or struck and lost by villagers from Point Hope or Wainwright during the fall season in 2007.

Subsistence hunting for bowhead whales at Barrow which may occur in either the Chukchi or Beaufort seas will be discussed here. Thirteen bowheads were landed at Barrow and nine were struck and lost during the spring hunt from 24 Apr through 27 May. Seven bowheads were landed at Barrow and three were struck and lost during the fall hunt from 7 through 11 Oct. Over the past 35 years, nearly all bowheads harvested in the fall have been taken from the Beaufort Sea. In 2007, all of the whales landed in the fall hunt at Barrow were taken in the Chukchi Sea. Suydam et al. (2008) suggested that the fact that sufficient numbers of whales were available in the Chukchi Sea during the fall in 2007 may be the result of an increased population size, changes in bowhead distribution or availability of food resources in the Chukchi Sea.

Beaufort Sea

Seismic Operations

Ice conditions precluded SOI's ability to collect seismic data in the Beaufort Sea in 2006. Ice conditions in the Beaufort Sea were favorable in 2007 and after completing a portion of the seismic survey work proposed for the Chukchi Sea in 2007, the *Gilavar* moved to the Beaufort Sea to collect seismic data at specific lease holdings (Fig. 2.2). Many of the SOI support vessels that operated in the Chukchi Sea also provided support for the seismic survey or research activities in the Beaufort Sea.

Dates of Operations

The *Gilavar* entered the Beaufort Sea on 12 Sep 2007. Prior to collecting seismic data in the Beaufort Sea, JASCO conducted sound source measurements of the airgun array on 17 and 18 Sep in Camden Bay near the area of SOI's proposed 2007 seismic survey activities. JASCO calculated preliminary disturbance and safety radii which were used by MMOs for mitigation during the survey activities. The methods used to conduct the sound source measurements and the results are discussed in detail in SOI's 2007 90–day report (Funk et al. 2008).

The *Gilavar* conducted seismic surveys in the Beaufort Sea from 18 Sep through 3 Oct and departed the Beaufort Sea on 8 Oct to conduct further seismic exploration in the Chukchi Sea. SOI completed ~791.7 km (491.9 mi) of deep–seismic production line in the Beaufort Sea in 2007. The analyses of marine mammal data collected during survey activities included periods during which airguns were firing such as ramp up, lead in, and lead out periods, and totaled ~1561 km (~968 mi) in the Beaufort Sea in 2007.

Location of Activities

The *Gilavar* conducted seismic survey activities at specific lease holding in the Beaufort Sea at the Sivulliq prospect located offshore of Flaxman Island (Fig. 2.2). Sound measurements from the small airgun array on the *Henry Christoffersen* (*Henry C.*) were conducted offshore of SOI's lease holding located northwest of Deadhorse.

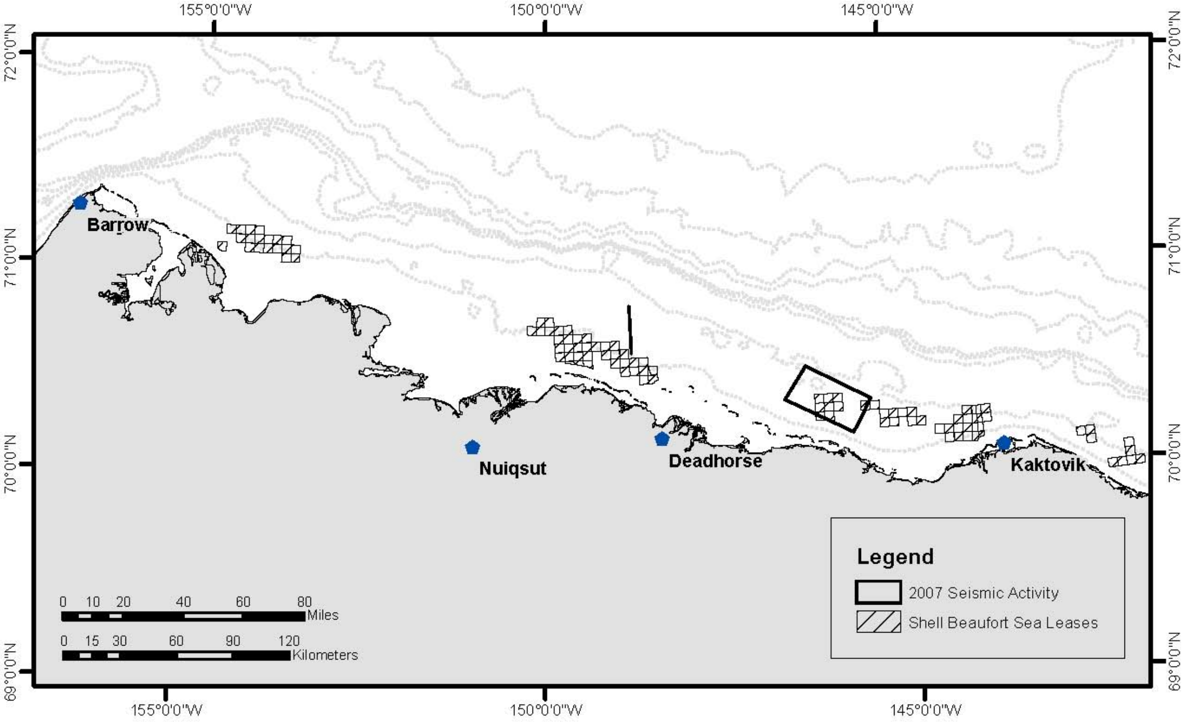


FIGURE 2.2. Location of SOI lease holdings in the Alaskan Beaufort Sea, SOI's deep seismic survey area between Deadhorse and Kaktovik, and the *Henry C*. airgun sound measurement northwest of Deadhorse.

Navigation and Airgun Description

The same system used for logging vessel position and speed, and shot locations described above for the Chukchi Sea was also used by the *Gilavar* in the Beaufort Sea. The airgun array used for seismic acquisition in the Beaufort Sea in 2007 was the same as that used for the Chukchi Sea and is described above and in SOI's 2007 90–day report (Funk et al. 2008).

Site Clearance and Shallow Hazards Surveys

In addition to deep seismic surveys in the Chukchi and Beaufort seas, SOI also conducted site clearance and shallow hazards surveys of potential exploratory drilling locations within SOI's lease areas and along potential pipeline routes in the Beaufort Sea as required by MMS regulations. Before drilling can begin, a site clearance survey and analysis is necessary to identify and/or evaluate potentially hazardous or otherwise sensitive conditions and sites at or below the seafloor that could affect the safety or appropriateness of operations. Examples of such conditions include subsurface faults, fault scarps, shallow gas, steep–walled canyons and slopes, buried channels, current scour, migrating sedimentary bedforms, ice gouging, permafrost, gas hydrates, unstable soil conditions, pipelines, anchors, ordnance, shipwrecks, or other geophysical or man–made features.

Various geophysical methods and tools were used to acquire graphic records of seafloor and sub–seafloor geologic conditions during the site clearance surveys. The data acquired and the types of investigations outlined below are performed routinely for most exploratory drilling and production facilities in marine areas, and for submarine pipelines, port facilities, and other offshore projects. High–resolution geophysical data such as two–dimensional, multi–channel seismic, medium penetration seismic, subbottom profiler, side scan sonar, multibeam bathymetry, magnetometer, and possibly piston core sediment sampling are typical types of data acquired. These data are interpreted to define geologic, geotechnical and archeological conditions at the site and to assess the potential engineering significance of these conditions. The following section provides a brief description of the operations and instrumentation used during SOI's 2007 Beaufort Sea site clearance program insofar as they may impact marine mammals.

Dates of Operations

Site clearance and shallow hazards surveys were conducted from the *Henry C.* which entered the Beaufort Sea on 17 Aug from Canada and sailed to the east side of Harrison Bay. The *Henry C.* remained anchored near Thetis Island until 30 Aug when JASCO conducted sound source measurements of the airgun array (comprised of two 10–in^3 airguns), and of a single 10–in^3 airgun that was to be used if mitigation became necessary. JASCO conducted a second sound source verification of the two–airgun array on 14 Sep near Camden Bay. The results of these two sound source measurements are described in SOI's 2007 90–day report (Funk et al. 2008). From 30 Aug through 3 Oct, site clearance operations were conducted in specific nearshore areas ranging from east of Kaktovik west to Thetis Island near the Colville River delta (Fig. 2.2). Site clearance survey activities occurred on ~23 days during this period. Other than during sound source measurements on 30 Aug and 14 Sep, the airgun array was operated only on 17–18 Sep near Camden Bay for ~12 hr. At all other times during site clearance surveys, the acoustical sources in use were lower–energy, medium– and higher–frequency sources as described below. On days when surveys did not occur, the *Henry C.* was usually transiting to a new site or anchored while waiting for bad weather to subside.

Location of Activities

The site clearance surveys were confined to very small, specific areas within defined OCS blocks from east of Kaktovik west to Thetis Island (Fig. 2.2). Small geophysical survey sources with limited energy output were employed to measure bathymetry, topography, geohazards, and other seabed characteristics.

Navigation

Throughout the survey the *Henry C's*. position, speed, and water depth were logged digitally every ~60 s. In addition, the position of the *Henry C.*, water depth, and information on the output of the airgun array or other geophysical tools were logged during all site clearance activities. The geophysics crew kept an electronic log of events, as did MMOs while they were on duty.

Airgun Description and Geophysical Tools Used for Site Clearance

An airgun cluster consisting of two 10–in^3 airguns was used during site clearance operations to locate potential hazards, such as gas deposits, at relatively shallow locations. Several other lower–energy acoustic sources were operated for shallow–penetration, subbottom surveys and to map the bottom. A bubble pulser operating at frequencies near 400 Hz was used for medium penetration and a Chirp sonar operating at 2–7 Hz was used for shallow penetration. Other acoustic sources included multibeam bathymetric sonar operating at 240 kHz and side–scan sonar operating at 190–210 kHz. Characteristics of this equipment are described in more detail in SOI's 2007 90–day report (Funk et al. 2008).

Beaufort Sea Construction (Pioneer)

Pioneer Natural Resources Alaska, Inc. (Pioneer) constructed a gravel drillsite, the Oooguruk Drillsite (ODS), in Harrison Bay offshore of the Colville River delta for future oil drilling and production operations. The ODS is located ~6 km (4 mi) southwest of Thetis Island and 15 km (9 mi) west of Oliktok Dock. Gravel was hauled to the ODS on ice roads during winter 2006 and stockpiled. Most of the island construction was accomplished in 2006. The flowline from the island to the mainland was installed during Feb through Apr 2007.

Construction of facilities on ODS began in Apr 2006 and continued through the 2007 open–water period. Ice–roads to the island were constructed during the ice–covered periods of 2005–2006 and 2006–2007. Installation of well–bay modules, drill rig and support complex, and the production warehouse began in Apr 2007 and continued through the 2007 open–water period. Drilling began during winter 2007–2008 with the first disposal well spudded on 16 Dec 2007. Heavy equipment used for construction activities included a Deer 750J bulldozer, Caterpillar 330C and 345B excavators, a Caterpillar 966 loader, and a Terex HC275 crane.

Pioneer used barges, crew vessels, and helicopters for the transportation of personnel and equipment to and from the ODS during the 2007 open–water period. Barge activity in support of Pioneer's ODS was conducted by Crowley Marine Systems and Bowhead Transportation. Barging activities began on 8 Jul and ended on 27 Sep. Barges MV *Garret*, MV *Greta Akpik*, MV *Stryker*, and the tug *Kavik River* and barge #210 made 129 round trips from Oliktok Dock to ODS during the 2007 open–water period (Table 2.2). Crew boats made 515 round trips to ODS during the same period (Table 2.2). In addition to the vessel traffic Pioneer completed ~650 helicopter round trips from the mainland to the ODS during Jul through Oct 2007.

TABLE 2.2. Number of barge and crew boat roundtrips between Oliktok Point and Pioneer's ODS during the 2007 open–water period.

Month	Barge	Crew Boat
July	32	112
August	61	183
September	36	198
October	0	22

Pioneer contracted JASCO and LGL to conduct acoustic studies of construction–related and vessel sounds at ODS, and aerial surveys of bowhead whales within 24–32 km (15–20 mi) of the island during the 2006 and 2007 open–water periods. The results of 2006 studies were reported by Zykov et al. (2007) and Reiser et al. (2008) and are discussed briefly in the Joint Monitoring Program comprehensive report for the 2006 open–water season (Funk et al. 2007). The results of the 2007 acoustic and aerial surveys were reported by Laurinolli et al. (2008) and Williams et al. 2008, and are summarized in Chapter 9.

Oil Production Operations (BP Northstar)

BP Exploration (Alaska), Inc. (BPXA) has been producing crude oil from Northstar Island, a man–made island in the Beaufort Sea, since late 2001. Northstar Island is located ~10 km (~6 mi) offshore, north of the Prudhoe Bay oil field. The gravel island serves as a work surface to support drilling and oil production facilities. Two subsea pipelines connect Northstar Island to the mainland. One pipeline transports production oil to existing facilities at Prudhoe Bay, and the other transports natural gas to the island for field injection and use in power generation.

Numerous types of activities are required to support oil production, which occurs throughout the year at Northstar. Oil field workers may live on the island for several weeks at a time, and various types of equipment are used for transport of personnel and supplies between West Dock and the island. Vessel traffic associated with transportation of personnel and equipment to and from Northstar Island is the most significant type of activity likely to affect the behavior of bowhead whales and other marine mammals during the open–water season. The vessel types include Bay class boats used as crew vessels, tug and barge traffic, a hovercraft, and helicopters used for transportation of crews and equipment. Table 2.3 enumerates the number of crew vessel, hovercraft, tug/barge, and helicopter round trips to Northstar Island during the 2007 open–water season.

Most well–drilling activity has been completed at Northstar, although periodic drilling activity occurs during the open–water period for well maintenance. This work usually involves the use of cables to lower equipment into the drill hole. New wells are also occasionally drilled above the formation.

Five gas turbines are located on Northstar Island: three Solar® generators for power generation and two GE LM–2500 high pressure compressors for gas injection. There is also a low–pressure compressor driven by a 5000 hp (3730 kW) electric motor running at a constant speed of 3600 rpm.

BPXA and its contractors have conducted numerous studies to monitor the effects of the Northstar development on marine mammals and the potential for Northstar activities to affect subsistence hunts for bowhead whales and seals. These studies have included pre– and post–development aerial surveys of ringed seals, and the use of trained dogs to study ringed seal use of lairs near Northstar. In addition, acoustic studies were done to determine the levels of various types of industrial sounds at Northstar Island during island construction, drilling, and production periods, and the attenuation of those sounds with distance from Northstar. Other acoustic studies focused on calling bowhead whales during the fall migration in an effort to determine what effects sounds generated from Northstar may have on the bowhead whale migration corridor. Descriptions of the various studies and their results are contained in annual and updated comprehensive reports (e.g., Richardson [ed.] 2008), annual summary reports (Richardson [ed.] 2007), and in 90–day reports submitted by BPXA to NMFS. In addition, a number of peer–reviewed articles and manuscripts have resulted from the Northstar marine mammal and acoustic studies program (e.g., Blackwell et al. 2004a,b; Blackwell and Greene 2005, 2006; Greene et al. 2004; Moulton et al. 2002, 2003, 2005; Williams et al. 2006). A summary of BP's 2007 acoustic program at Northstar is contained in Chapter 9.

Barging and Other Vessels

In addition to the localized barge and vessel traffic described above in support of oil production and development by Pioneer and BPXA, other barge traffic occurred from Barrow to the Canadian border during the 2007 open–water period (Table 2.4). Barging activities in the Beaufort Sea in 2007 were conducted in support of industry and other activities from Cape Simpson to Bullen Point. In addition, Island Tug and Barge conducted two barge round trips of the Beaufort Sea from mid–Aug to the late Sep, and Crowley Marine Services conducted barge activity from Barrow to Lonely and Kaktovik between early Aug and late Sep.

Whaling Activities

Subsistence whaling activities are conducted in the Beaufort Sea at Barrow, Nuiqsut (Cross Island), and Kaktovik. Whaling activities at Barrow are also conducted in the Chukchi Sea and the 2007 subsistence hunt at Barrow is discussed in the Chukchi Sea section. Spring whaling activities are not conducted at Cross Island and Kaktovik. Three bowhead whales were landed by villagers at both Kaktovik and Cross Island during the fall season from 31 Aug through 11 Sep. One whale was struck and lost at Cross Island on 15 Sep.

TABLE 2.3. Number of barge, hovercraft, crew boat, and helicopter round trips to BP's Northstar Island by month during the 2007 open–water period.

Month	Barges	Hovercraft	Crew Boats	Helicopter
July	3	97	22	17
August	32	100	41	3
September	4	36	71	42
October	1	18	3	112

TABLE 2.4. Barge activity in support of industry and other activity in the Beaufort Sea during the 2007 open–water period.

Vessel	Type	Period	Location
Greta Akpik	Landing craft	Late July to late Aug.	6 R/T Cape Simpson to West dock
Greta Akpik	Landing craft	Mid-Aug.	1 R/T West Dock to Kaktovik
Greta Akpik	Landing craft	Mid- to late Aug.	10 R/T West Dock to Bullen Point
Greta Akpik	Landing craft	Mid-Aug.	1 R/T West Dock to Barrow
Greta Akpik	Landing craft	Late Aug.	Bullen Point to Barrow
Nunaniq	Landing craft	Early Aug.	Barrow to Cape Simpson
Nunaniq	Landing craft	Mid- to late Aug.	4 R/T Cape Simpson to West dock
Nunaniq	Landing craft	Late Aug.	Cape Simpson to Lonely to Barrow
Nunaniq	Landing craft	Late Aug.	Lonely to Barrow
Island Monarch/ Island Trader	Tug and barge	Mid- Aug. to late Sept.	Two R/T transits of Beaufort Sea

Area–wide Monitoring

The MMS conducts the Bowhead Whale Aerial Survey Program (BWASP) annually to monitor fall migration in the Beaufort Sea. The goals of the program are to:

- define the annual fall migration of bowhead whales, and significant inter–year differences and long–term trends in the distance from shore and water depth at which whales migrate.
- monitor temporal and spatial trends in the distribution, relative abundance, habitat, and behaviors (especially feeding) of bowhead whales in arctic waters.
- provide real–time data to MMS and NMFS on the general progress of the fall migration of bowhead whales across the Alaskan Beaufort Sea.
- provide an objective area–wide context for management interpretation of the overall fall migration of bowhead whales and site–specific study results.
- record and map beluga whale distribution and incidental sighting of other marine mammals.
- determine seasonal distribution of bowhead whales in other planning areas of interest to MMS.

The most recent report on the results of the aerial survey program includes information on the 2002–2004 fall migration (Monnett and Treacy 2005). Reports of the results for subsequent years will be forthcoming.

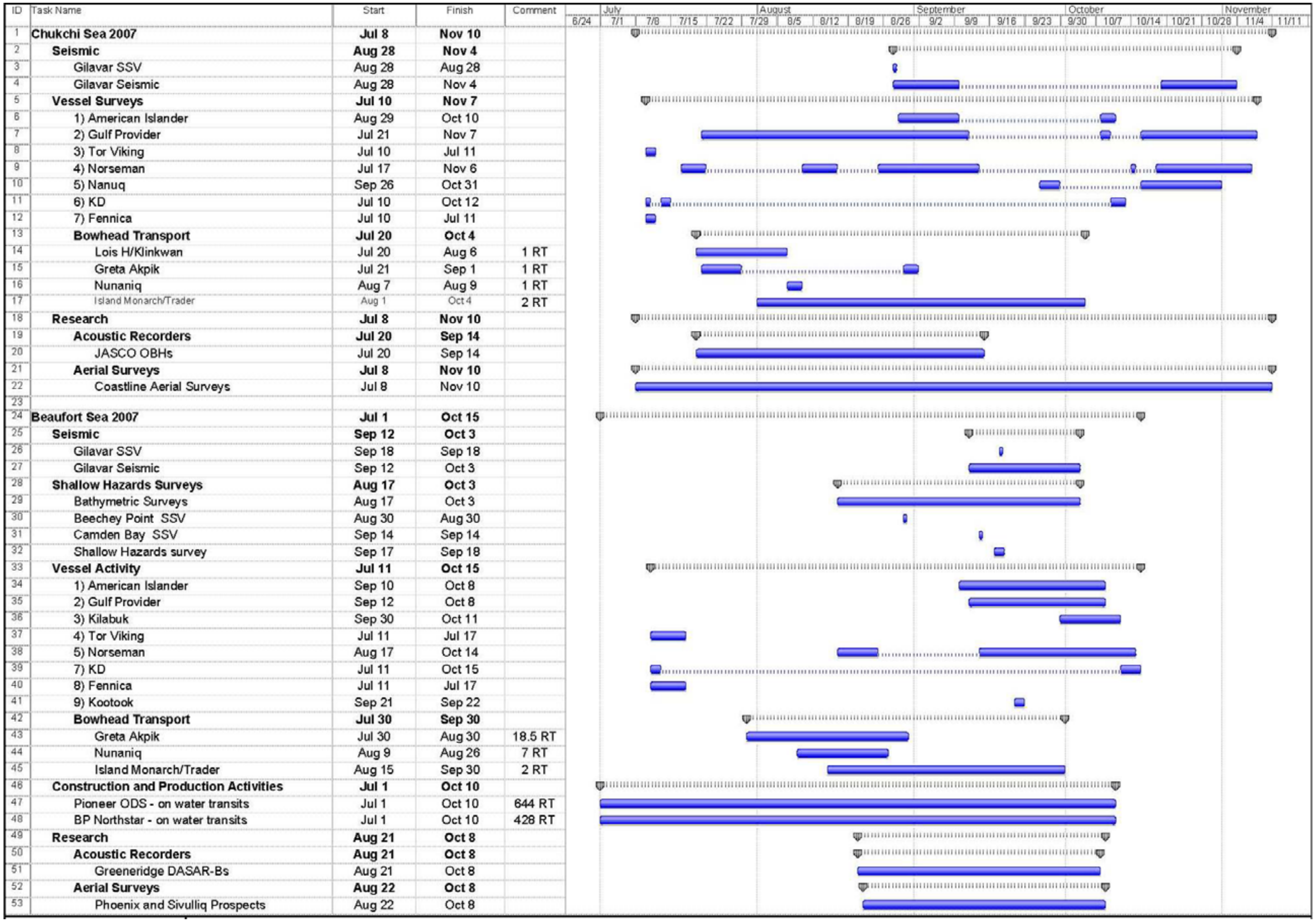
The Alaska Department of Fish and Game initiated a bowhead whale satellite tagging study during the spring migration past Barrow in 2006. Two bowheads were tagged, one in the spring (May) and a second in the fall Sep. In a collaborative effort involving whalers from Katovik; Aklavik Hunters and Trappers Committee, Canada; Department of Fisheries and Oceans Canada; Ministry of Agriculture and Lands, British Columbia, Canada; Alaska Department of Fish and Game; and Greenland Institute of Natural Resources, five whales were tagged in the Northwest Territories, Canada and three whales were tagged near Barrow in the fall 2007. A description of the program and results of the study are summarized online at: http://wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead.

Aerial surveys were included as part of the Study of the Northern Alaska Coastal System (SNACS) to collect information on bowhead whale distribution and habitat use in an area northeast of Barrow. The SNACS was initiated in 2005 and is funded by the National Science Foundation. The study involves researchers from the various universities, the National Marine Mammal Laboratory (NMML), and the North Slope Borough, and was ongoing in 2007. Reports on the results of the SNACS will be forthcoming.

The Bowhead Whale Feeding Ecology Study (BOWFEST) is a multidisciplinary study involving oceanographic sampling, vessel–based observations, a tagging operation, acoustic monitoring, and aerial surveys in an area northeast of Barrow. BOWFEST was initiated by NMML in 2007 and the results of the 2007 aerial survey component (Goetz et al. 2008) are summarized in Chapter 9.

Regional Timeline of Activities

A Gantt chart showing the time periods during which activities described in this report took place is presented in Fig. 2.3. Figures 2.4 – 2.12 are maps showing the general locations of activities described in this report.



ID	Task Name	Start	Finish	Comment
1	**Chukchi Sea 2007**	**Jul 8**	**Nov 10**	
2	**Seismic**	**Aug 28**	**Nov 4**	
3	Gilavar SSV	Aug 28	Aug 28	
4	Gilavar Seismic	Aug 28	Nov 4	
5	**Vessel Surveys**	**Jul 10**	**Nov 7**	
6	1) American Islander	Aug 29	Oct 10	
7	2) Gulf Provider	Jul 21	Nov 7	
8	3) Tor Viking	Jul 10	Jul 11	
9	4) Norseman	Jul 17	Nov 6	
10	5) Nanuq	Sep 26	Oct 31	
11	6) KD	Jul 10	Oct 12	
12	7) Fennica	Jul 10	Jul 11	
13	**Bowhead Transport**	**Jul 20**	**Oct 4**	
14	Lois H/Klinkwan	Jul 20	Aug 6	1 RT
15	Greta Akpik	Jul 21	Sep 1	1 RT
16	Nunaniq	Aug 7	Aug 9	1 RT
17	Island Monarch/Trader	Aug 1	Oct 4	2 RT
18	**Research**	**Jul 8**	**Nov 10**	
19	**Acoustic Recorders**	**Jul 20**	**Sep 14**	
20	JASCO OBHs	Jul 20	Sep 14	
21	**Aerial Surveys**	**Jul 8**	**Nov 10**	
22	Coastline Aerial Surveys	Jul 8	Nov 10	
23				
24	**Beaufort Sea 2007**	**Jul 1**	**Oct 15**	
25	**Seismic**	**Sep 12**	**Oct 3**	
26	Gilavar SSV	Sep 18	Sep 18	
27	Gilavar Seismic	Sep 12	Oct 3	
28	**Shallow Hazards Surveys**	**Aug 17**	**Oct 3**	
29	Bathymetric Surveys	Aug 17	Oct 3	
30	Beechey Point SSV	Aug 30	Aug 30	
31	Camden Bay SSV	Sep 14	Sep 14	
32	Shallow Hazards survey	Sep 17	Sep 18	
33	**Vessel Activity**	**Jul 11**	**Oct 15**	
34	1) American Islander	Sep 10	Oct 8	
35	2) Gulf Provider	Sep 12	Oct 8	
36	3) Kilabuk	Sep 30	Oct 11	
37	4) Tor Viking	Jul 11	Jul 17	
38	5) Norseman	Aug 17	Oct 14	
39	7) KD	Jul 11	Oct 15	
40	8) Fennica	Jul 11	Jul 17	
41	9) Kootook	Sep 21	Sep 22	
42	**Bowhead Transport**	**Jul 30**	**Sep 30**	
43	Greta Akpik	Jul 30	Aug 30	18.5 RT
44	Nunaniq	Aug 9	Aug 26	7 RT
45	Island Monarch/Trader	Aug 15	Sep 30	2 RT
46	**Construction and Production Activities**	**Jul 1**	**Oct 10**	
47	Pioneer ODS - on water transits	Jul 1	Oct 10	644 RT
48	BP Northstar - on water transits	Jul 1	Oct 10	428 RT
49	**Research**	**Aug 21**	**Oct 8**	
50	**Acoustic Recorders**	**Aug 21**	**Oct 8**	
51	Greeneridge DASAR-Bs	Aug 21	Oct 8	
52	**Aerial Surveys**	**Aug 22**	**Oct 8**	
53	Phoenix and Sivulliq Prospects	Aug 22	Oct 8	

FIGURE 2.3. Gantt chart showing the timing and duration of activities described in this report. The gray bars indicate the approximate duration of each category of activity and the blue bars indicate the duration of specific activities that occurred within each category.

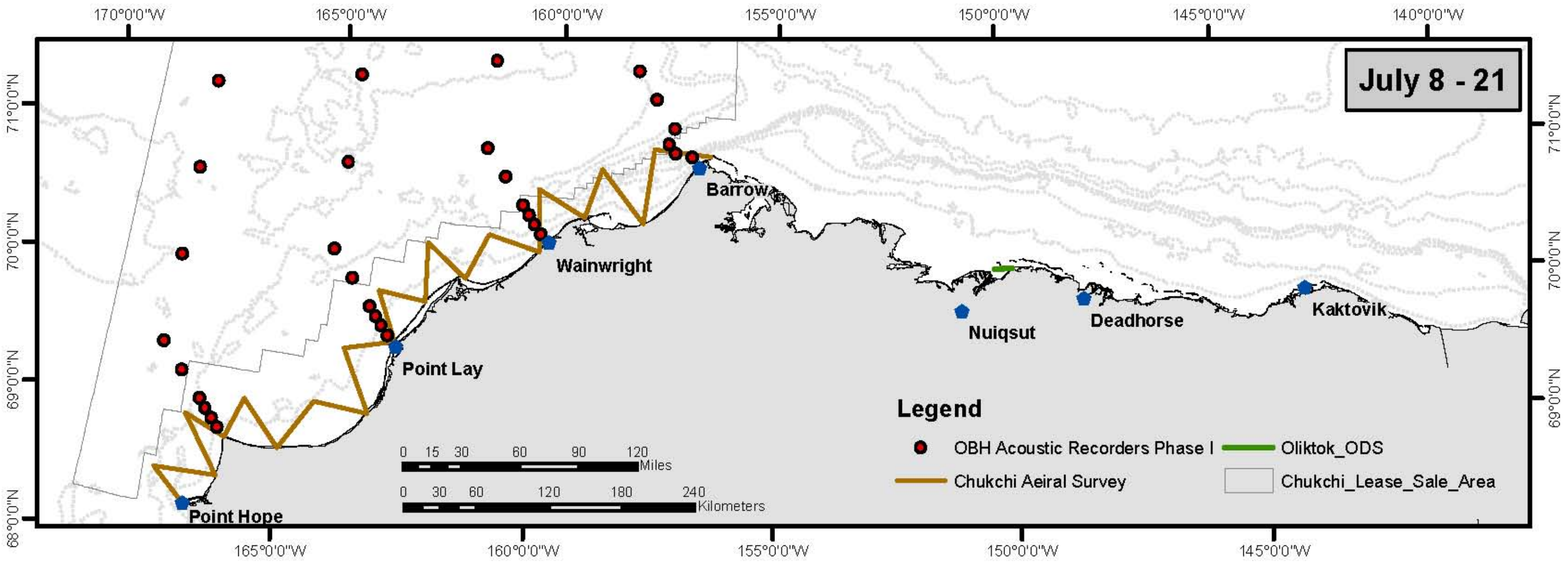


FIGURE 2.4. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 8–21 Jul 2007.

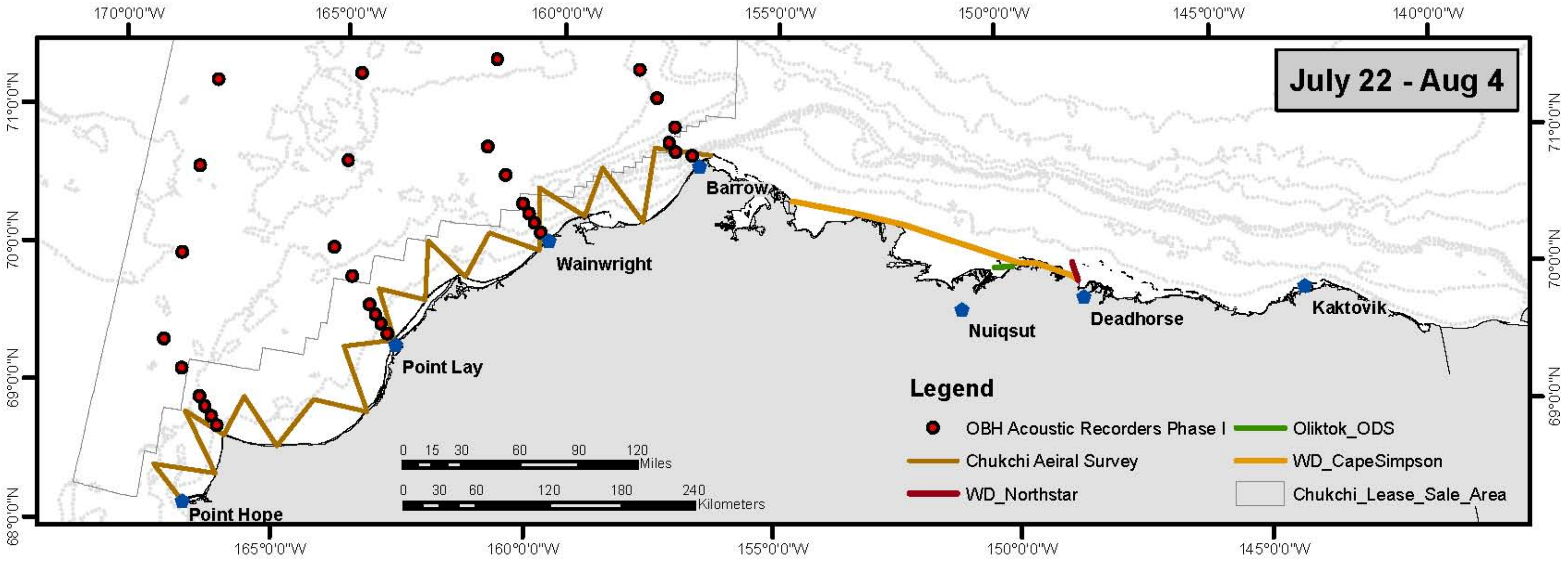


FIGURE 2.5. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 22 Jul to 4 Aug 2007.

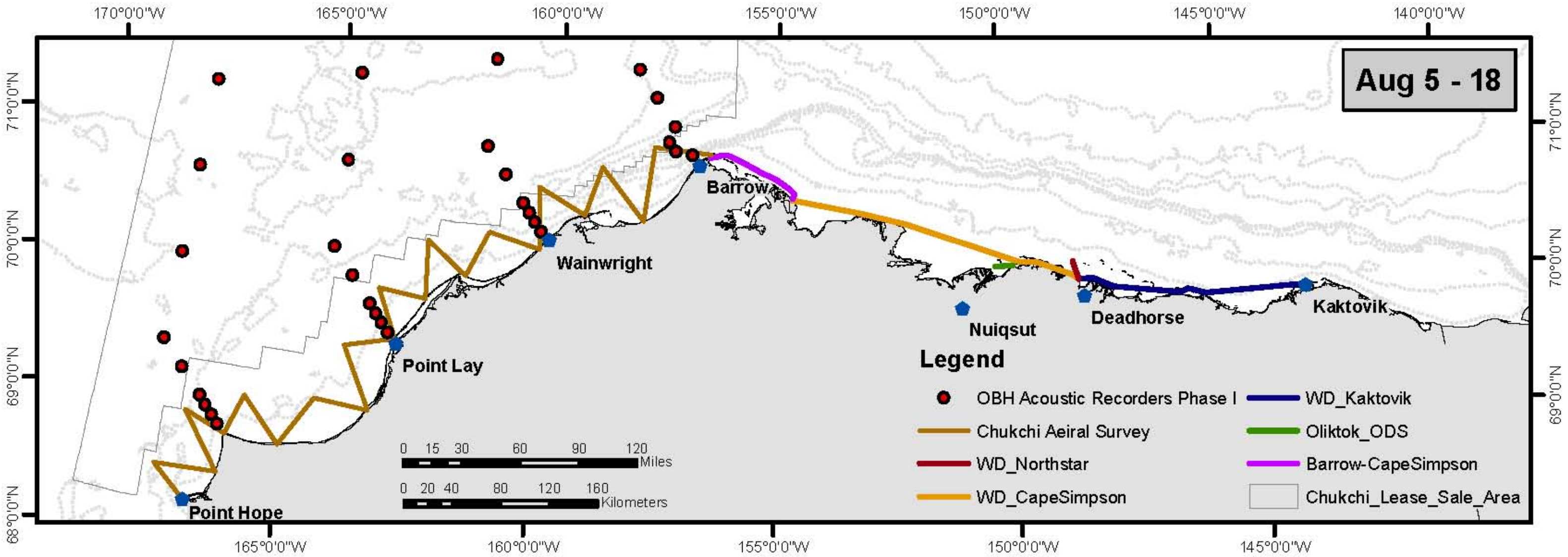


FIGURE 2.6. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 5 to 18 Aug 2007.

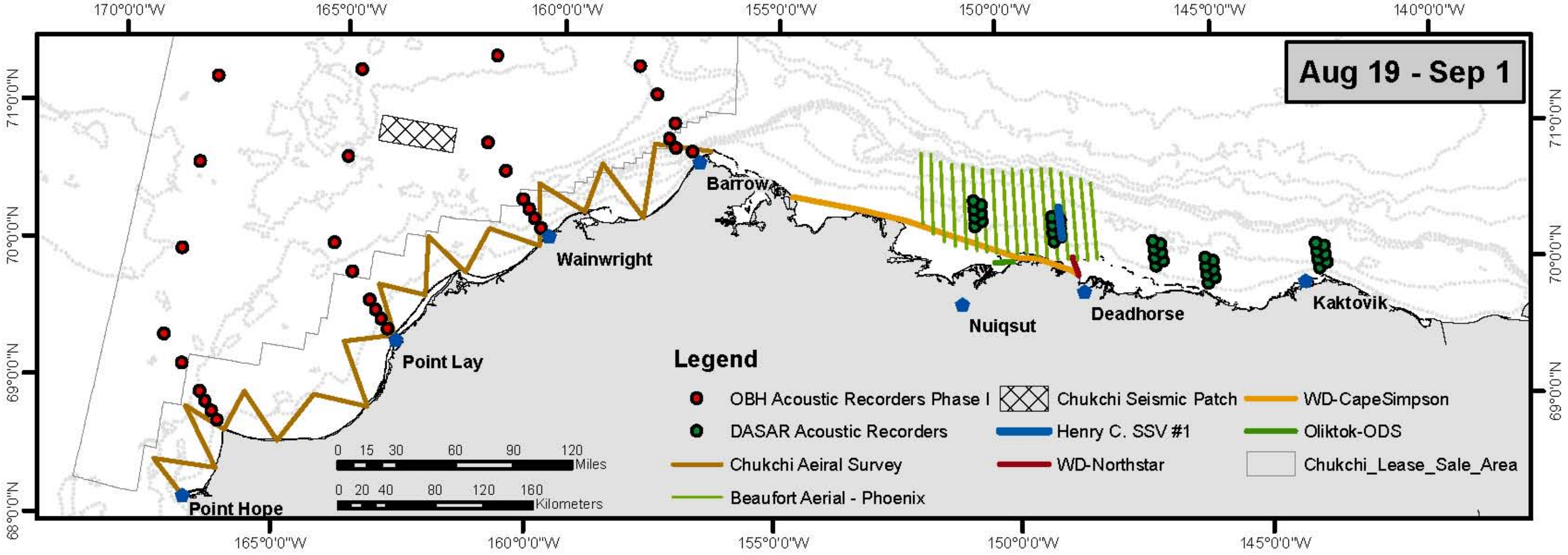


FIGURE 2.7. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 19 Aug to 1 Sep 2007.

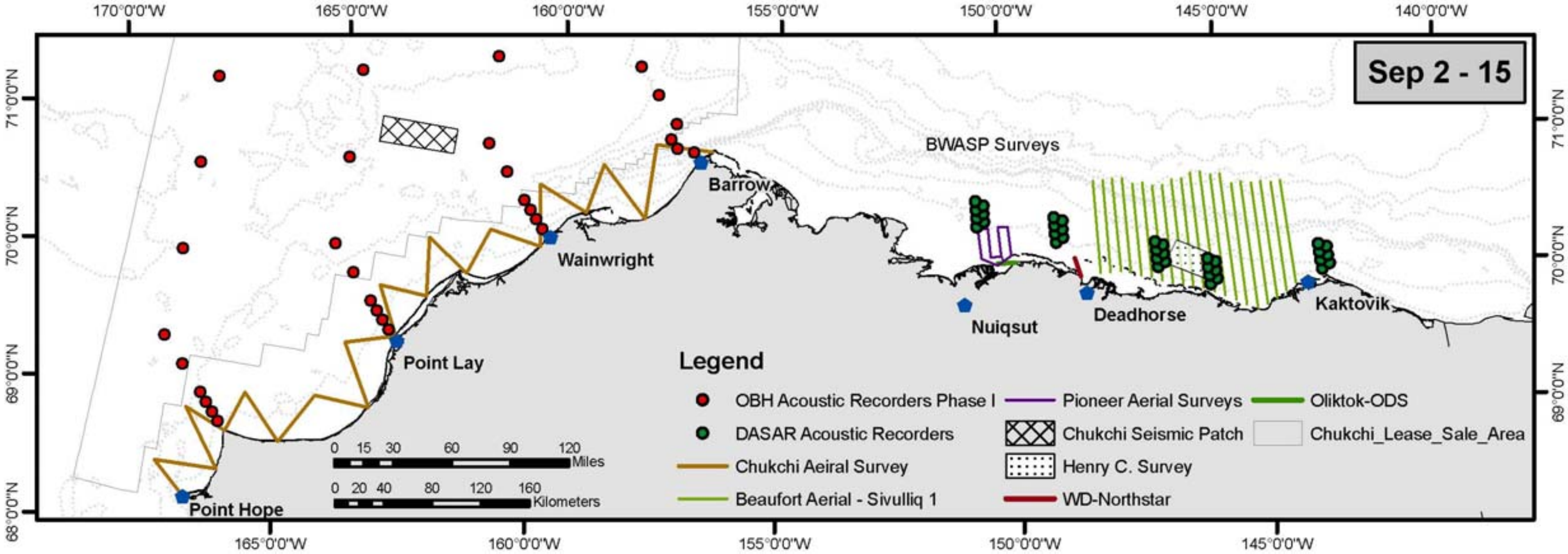


FIGURE 2.8. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 2 to 15 Sep 2007.

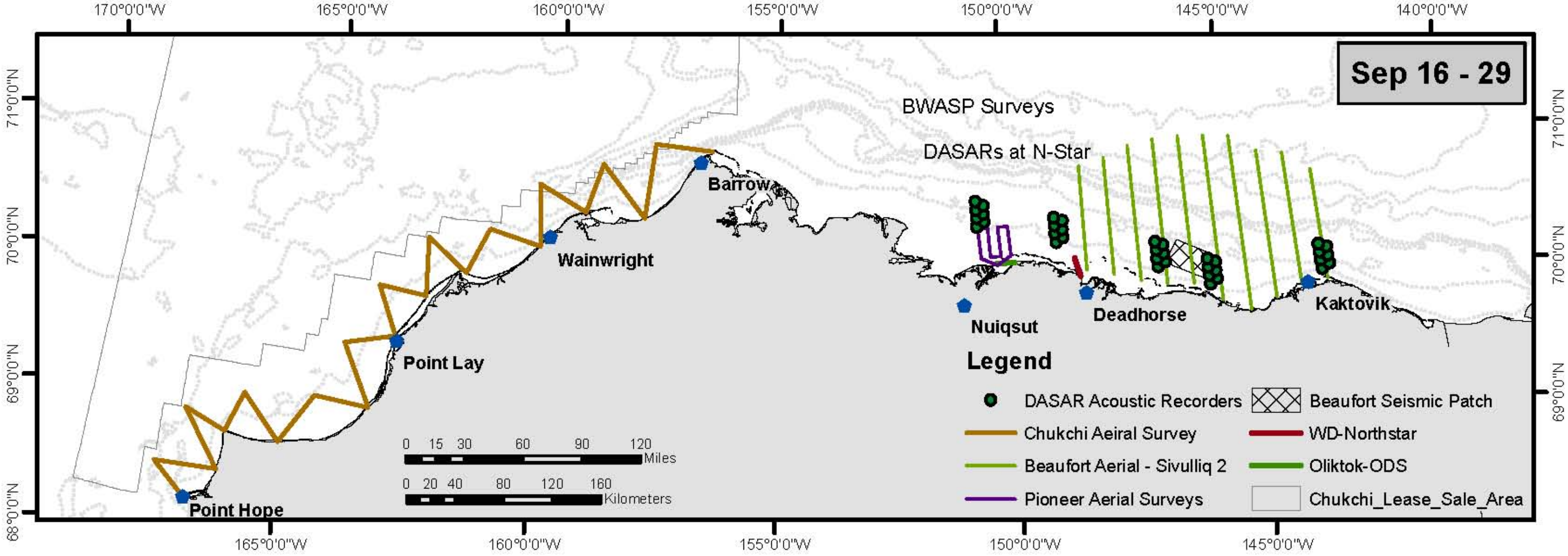


FIGURE 2.9. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 16 to 29 Sep 2007.

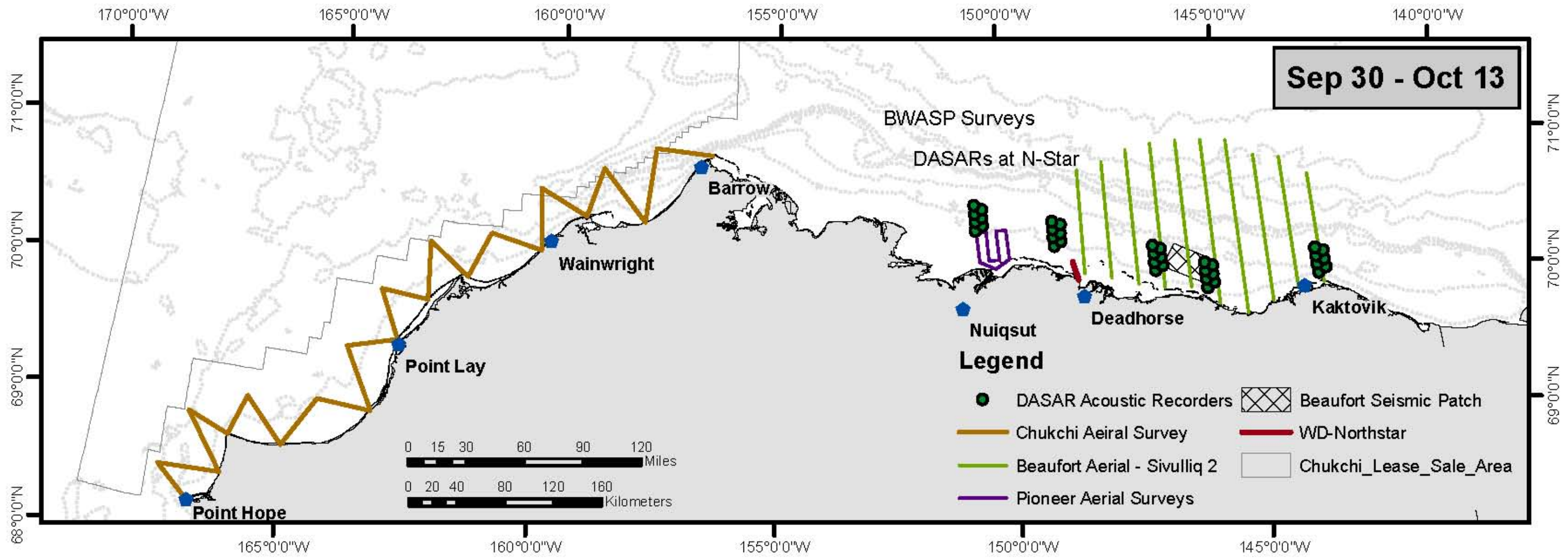


FIGURE 2.10. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 30 Sep to 13 Oct 2007.

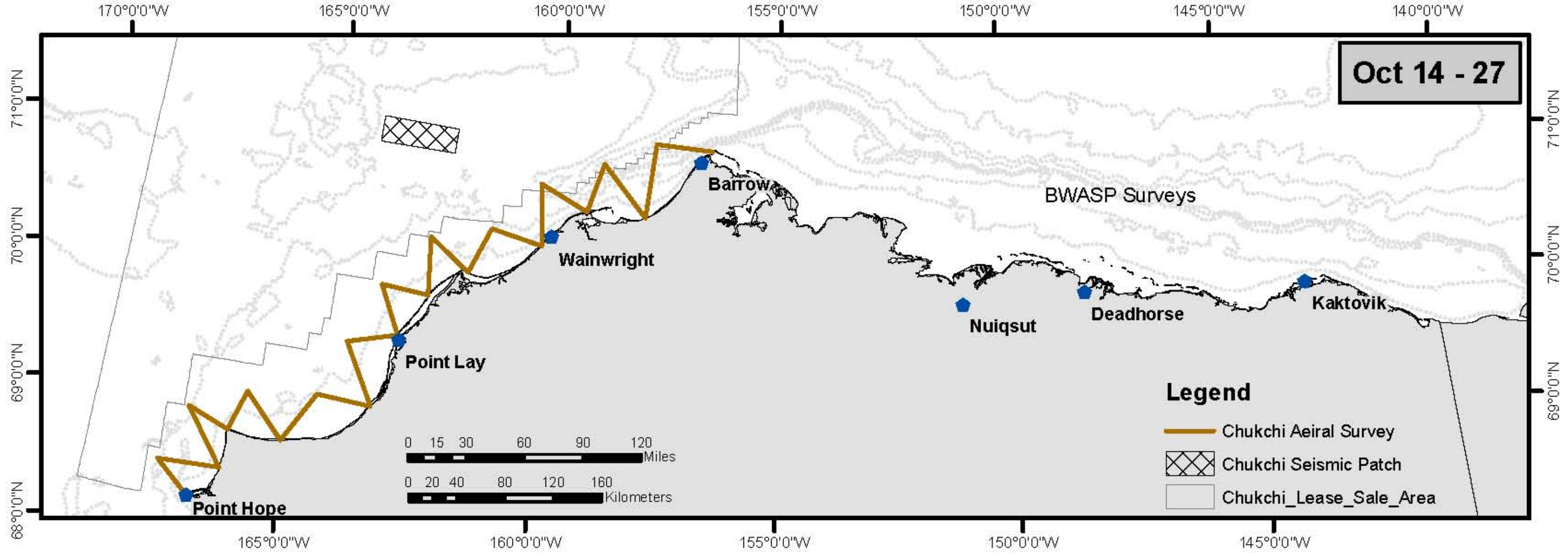


FIGURE 2.11. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 14 to 27 Oct 2007.

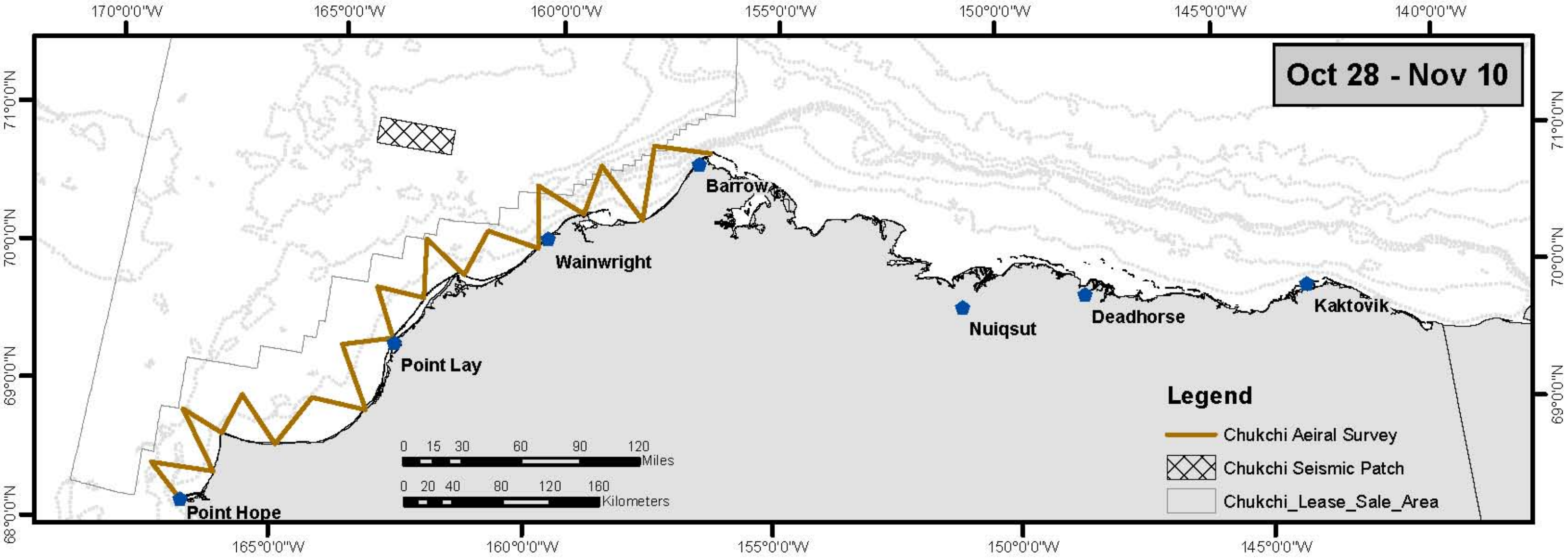


FIGURE 2.12. Activities that occurred or were ongoing in the Chukchi and Beaufort seas from 28 Oct to 10 Nov 2007.

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3. CHUKCHI SEA VESSEL–BASED MONITORING PROGRAM[1]

INTRODUCTION

This chapter presents data collected during the marine mammal monitoring and mitigation program aboard vessels operating in the Chukchi Sea in 2006 and 2007 in support of seismic data acquisition for Shell Offshore Inc. (SOI), ConocoPhillips Alaska Inc. (CPAI), and GX Technology (GXT). Summaries of the 2007 data are presented and compared to those of the 2006 data. Where appropriate, the 2006 and 2007 data have been pooled to allow for multi–year analyses with increased power due to greater sample size. English unit equivalents of tables and figures showing data in metric units in this chapter and following chapters are available in Appendix E.

Environmental conditions, ice cover in particular, varied greatly between 2006 and 2007. In order to make direct comparisons of the area covered by ice between years possible, a standard area was defined in which to measure ice coverage (Fig. 3.1). Between early Jul and mid–Nov the average area covered by ice in this portion of the Chukchi Sea was 45,117 km^2 (17,420 mi^2) in 2006, compared to 12,448 km^2 (4806 mi^2) in 2007 (Fig. 3.2). Different environmental conditions between years likely had different biological effects on marine mammal distribution and behavior that are not possible to quantify at this time.

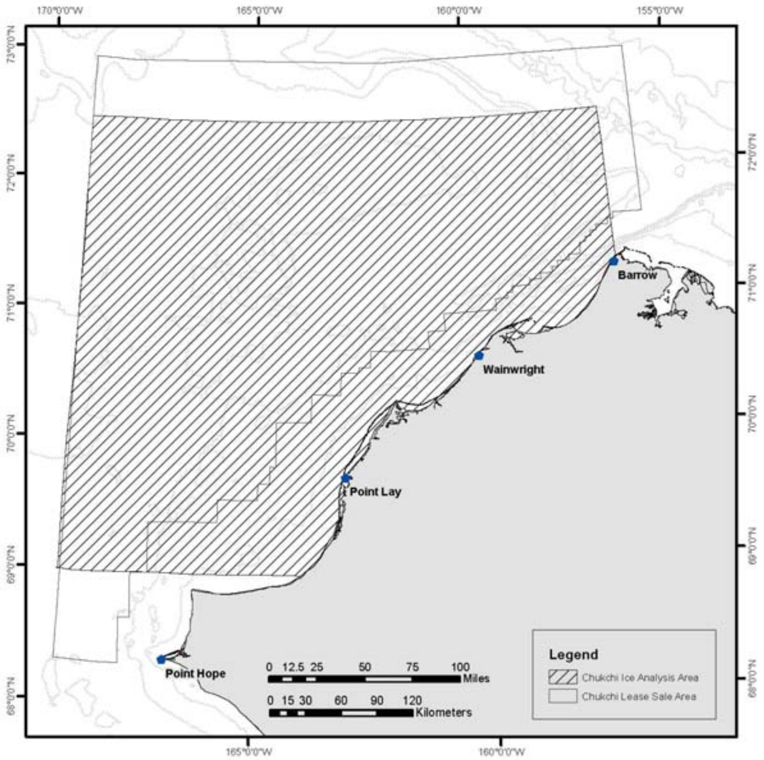

FIGURE 3.1. Shaded area represents the area used to estimate ice cover in the Chukchi Sea. SOI provided detailed ice cover data for this area.

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[1] By Craig Reiser, Beth Haley, Danielle Savarese, and Darren Ireland

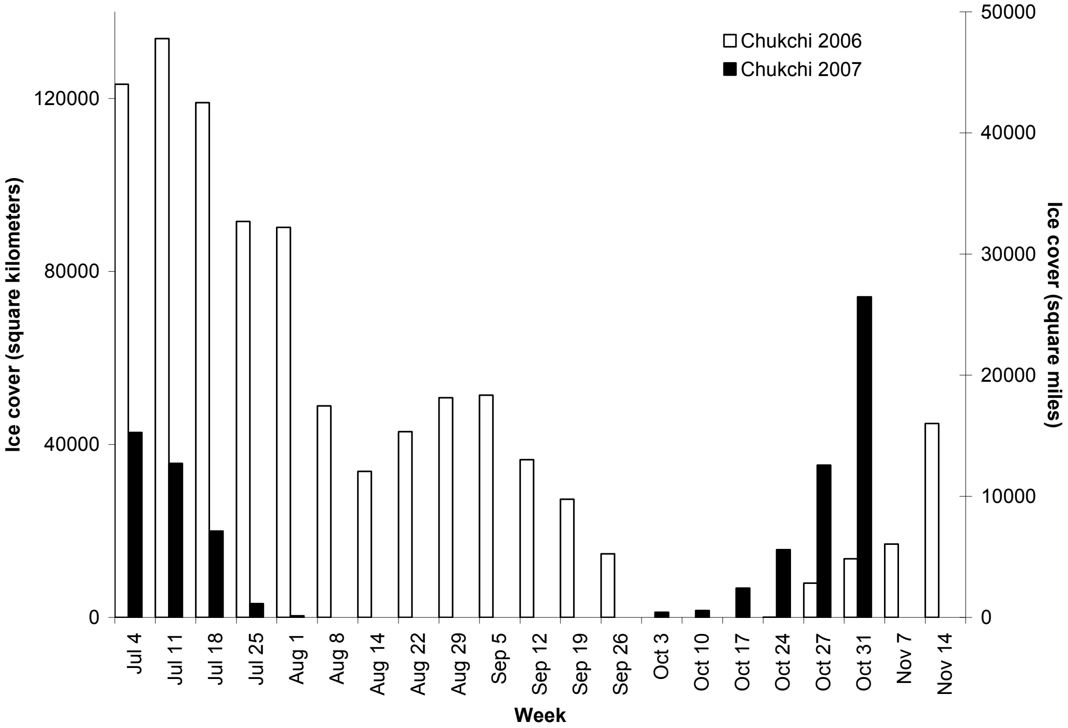

FIGURE 3.2. Ice cover in the Chukchi Sea by week in 2006 and 2007.

Among the marine mammals known to occur within the project area, nine are cetaceans, five are pinnipeds, and one is an ursid (the polar bear). Three cetacean species, bowhead, humpback, and fin whales, are listed as endangered under the U.S. Endangered Species Act (ESA). Humpback and fin whales are not common in the Chukchi Sea (Angliss and Outlaw 2007). Details on the abundance, distribution, and conservation status of the marine mammal species likely to occur in the project area can be found in Appendix F in the 90–day report for the 2007 seismic program (Funk et al. 2008).

METHODS

Monitoring Tasks

The main purposes of the vessel–based monitoring program were to ensure that the provisions of the IHAs issued by NMFS and USFWS were satisfied, effects on marine mammals were minimized, and residual effects on animals were documented. Tasks specific to monitoring included:

- Use dedicated marine mammal observers (MMOs) to visually monitor the occurrence and behavior of marine mammals near the airguns when the airguns are operating and during a sample of the times when they are not.
- Use the visual monitoring data as a basis for implementing the required mitigation measures.
- Visually monitor the occurrence and behavior of marine mammals near support vessels when underway.
- Use support vessels to conduct visual surveys of areas where airgun sounds could reach received levels of ≥160 dB re 1 μPa (rms).
- Record (insofar as possible) the effects of the airgun operations and the resulting sounds on marine mammals.

Safety and Potential Disturbance Radii

Under current NMFS guidelines (e.g., NMFS 2000), "safety radii" for marine mammals around airgun arrays are customarily defined as the distances within which received pulse levels are ≥180 and 190 dB re 1 µPa (rms) for cetaceans and pinnipeds, respectively. The ≥180 and 190 dB (rms) guidelines were also required by the USFWS for the species under its jurisdiction (walrus and polar bear, respectively). These safety criteria are based on an assumption that seismic pulses at lower received levels will not injure these animals or impair their hearing abilities, but that higher received levels might have some such effects. Marine mammals exposed to ≥160 dB (rms) are assumed by NMFS to be potentially subject to behavioral disturbance. However, for certain groups (dolphins, pinnipeds), available data suggest that disturbance is unlikely to occur unless received levels are higher, perhaps ≥170 dB (rms) for an average animal (Richardson et al. 1995; Richardson and Würsig 1997; Stone 2003).

There has recently been concern that received pulse levels as low as 120 dB (rms) may have the potential to elicit behavioral responses from bowhead whales during fall migration. In 2006 there was a requirement in the IHA issued by NMFS to implement special mitigation measures if specified numbers of bowhead cow/calf pairs (four) were detected within an acoustically verified 120 dB (rms) monitoring zone in the Chukchi Sea beginning no later than 25 Sep. Special mitigation measures were also required if large groups (≥12 individuals) of non–migratory balaenopterid whales were detected within an acoustically verified 160 dB (rms) zone ahead of or perpendicular to the seismic vessel.

Chukchi Sea 2006–07.—Field measurements of received airgun sounds as a function of distance and aspect from the source vessel were made for all airgun sources in 2006 and 2007 prior to or coincident with the beginning of seismic data acquisition by JASCO Research Ltd. or Greeneridge Sciences, Inc (Table 3.1). The 24–airgun, 3147 in^3 array towed by the *Gilavar* for SOIs seismic surveys was the only array used and measured in both years. The 2007 measured radii were similar to, but in most cases slightly greater than the 2006 measured radii. This may have resulted from differences in measurement locations or in oceanographic characteristics between years. The distances presented in Table 3.1 are those used for analyses of relevant data in this chapter and Chapter 6.

TABLE 3.1. Comparison of measurements of the ≥190, 180, 170, 160 and 120 dB rms distances (in km) for sound pulses from seismic survey airgun arrays deployed in the Chukchi Sea, Alaska, 2006 and 2007.

	Seismic Airgun Arrays				Mitigation Airgun
	Patriot	*Discover*	*Gilavar*	*Gilavar*	*Gilavar*
	16 airguns	36 airguns	24 airguns	24 airguns	1 airgun
Received Level (dB rms)	3390 in^3	3320 in^3	3147 in^3	3147 in^3	30 in^3
	2006	2006	2006	2007	2007
≥190	0.517	0.480	0.460	0.550	0.010
≥180	1.628	1.770	1.400	2.470	0.024
≥170	4.689	5.110	4.720	4.500	0.076
≥160	11.431	10.970	7.990	8.100	1.360
≥120	75.400	166.960	82.890	66.000	41.100

Visual Monitoring Methods

Vessel–Based Monitoring—Chukchi and Beaufort Seas

Visual monitoring methods aboard seismic source vessels and support vessels were designed to meet the requirements in the IHAs. The primary purposes of MMOs aboard the seismic, shallow hazards, and support vessels were as follows: ***(1)*** Conduct monitoring and implement mitigation measures to avoid or minimize exposure of cetaceans and walruses to airgun sounds with received levels ≥180 dB re µPa (rms), or of other pinnipeds and polar bears to ≥190 dB. ***(2)*** Conduct monitoring and implement mitigation measures to avoid or minimize exposure of groups of 12 or more non–migratory balaenopterid whales to airgun sounds with received levels ≥160 dB (rms). ***(3)*** Document numbers of marine mammals present, any reactions of marine mammals to seismic activities, and whether there was any possible effect on accessibility of marine mammals to subsistence hunters in Alaska. Results of the vessel–based monitoring effort in the Chukchi Sea are presented in this chapter and from the Beaufort Sea in Chapter 6.

The visual monitoring methods that were implemented during seismic exploration were very similar to those used during various previous seismic cruises conducted under IHAs since 2003. In summary, during the seismic and shallow–hazards surveys in the Chukchi and Beaufort seas, at least one MMO onboard the source vessel maintained a visual watch for marine mammals during all daylight hours while seismic or shallow–hazards surveys were underway. Observers focused their search effort forward and to the sides of the vessel but also searched aft of the vessel occasionally while it was underway. Safety radii for the *Henry C.*, which was used for shallow–hazard surveys in the Beaufort Sea, were considerable smaller than those of the deep seismic source vessels, and observers monitored to the aft of the vessel a greater proportion of the time than on the larger source vessels. Watches were conducted with the unaided eye, Fujinon 7 × 50 reticle binoculars, and Zeiss 20 × 60 image stabilized binoculars. MMOs instructed seismic operators to power down or shut down the airguns if marine mammals were sighted near or about to enter the appropriate safety radii.

MMOs onboard support vessels conducted watches similar to those of MMOs onboard the source vessels. MMOs onboard support vessels (referred to as chase/monitoring vessels in SOI's 2007 90–day report) worked directly with the source vessels to notify MMOs onboard the source vessels if groups of bowhead or gray whales (or bowhead cow/calf pairs) were sighted within the 160 dB radius, allowing the source vessel to implement appropriate mitigation. The sizes of the 180 dB safety radii around the *Gilavar* in 2007 in the Chukchi Sea (2.47 km or 1.5 mi) and in the Beaufort Sea (2.25 km or 1.4 mi) were near the limit within which MMOs can reliably detect marine mammals. Therefore, SOI voluntarily implemented a protocol in 2007 that used two chase/monitoring vessels to help monitor the safety zones. During most seismic operations from the *Gilavar* in 2007 two chase/monitoring vessels traveled 1–2 km (0.6–1.2 mi) ahead of and 1 km (0.6 mi) to either side of the *Gilavar's* trackline. When necessary to meet permit requirements, one of the two vessels moved further ahead to monitor the 160 dB zone. MMOs aboard the chase/monitoring boats monitoring the 160 dB zone called the *Gilavar* MMOs and alerted them to the position of all observed marine mammals. MMOs aboard the *Gilavar* then initiated any necessary mitigation measures.

Various factors including high sea conditions (determined using Beaufort wind force), poor visibility, and MMO experience can make identification of marine mammals difficult, and both cetaceans and pinnipeds could not always be identified to species. Differentiating ringed from spotted seal was especially difficult and these two species along with unidentified seal sightings were combined into one category for analyses. Most of the unidentified seals were likely ringed seals given the known densities of seals in the Chukchi and Beaufort seas.

Analyses

Categorization of Data

Observer effort and marine mammal sightings were divided into several analysis categories related to environmental conditions and vessel activity. The categories were similar to those used during various other recent seismic studies conducted under IHAs (e.g., Holst et al. 2005a,b; Ireland et al. 2005, 2007a,b; Patterson et al. 2007).

Study Area and Seasons.—Data were categorized by the geographic region and time period during which they were collected (Fig. 3.3). Only sightings and effort from vessel activities north of Point Hope (68.34 °N) and west of Pt. Barrow were included in the Chukchi Sea study area and east of Pt. Barrow to 141° W longitude included in the Beaufort Sea study area (Chapter 6). The "summer" period included sightings and effort during the months of Jun–Aug while the "fall" period included sightings from Sep–Nov.

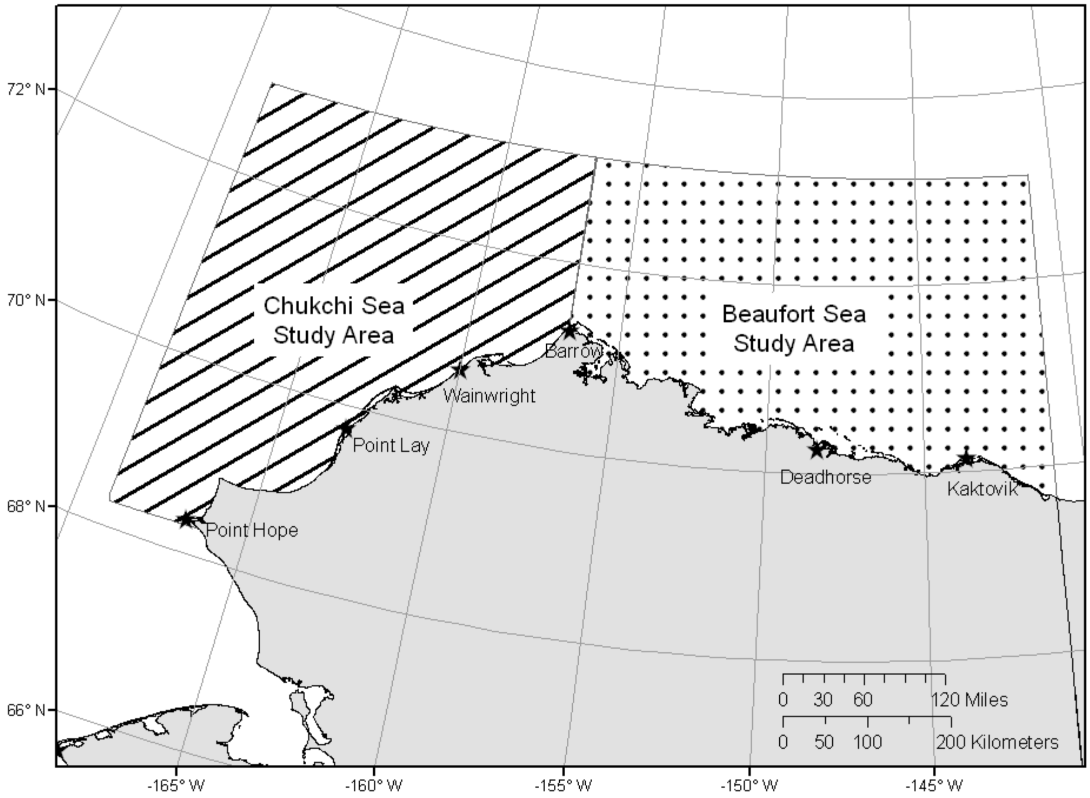

Figure 3.3. The Chukchi Sea and Beaufort Sea study area boundaries used to categorize data for analysis and presentation.

Useable Data.—Data were categorized as "useable" or "non–useable" for purposes of comparison and for the calculation of densities. Effort and sightings were defined as "useable" when made during daylight periods excluding

- periods 3 min to 1 h for pinnipeds and polar bears, or 2 h for cetaceans, after the airguns were turned off (post–seismic), or

- periods when another vessel was within 1 km (0.6 mi) for pinnipeds and ursids, and 5 km (3.1 mi) for cetaceans, due to the potential for the presence of other vessels to alter the distribution of animals;
- when ship speed was <3.7 km/h (2 kt), or
- periods with seriously impaired sightability. (This included all nighttime observations, and daytime periods with one or more of the following: visibility <3.5 km or 2.2 mi, Beaufort wind force (Bf) >5 (Bf >2 for minke whales, belugas, and porpoises), or >60º of severe glare between 90º left and 90º right of the bow.)

Seismic Periods.—In general, data were categorized as "seismic", "non–seismic", or "post–seismic". Seismic included all data collected from the source vessels while the airguns were operating. Non–seismic included all data obtained before the airguns were activated (pre–seismic) or >1 or >2 h (for pinnipeds/polar bears and cetaceans, respectively) after all airguns were deactivated. Post–seismic periods were from 3 min to 1 h (for pinnipeds and polar bears) or 2 h (for cetaceans) after cessation of seismic activity and were excluded from most analyses. Thus, the post–seismic data (3 min to 1 or 2 h after cessation of seismic activity) were not included in either the seismic or non–seismic categories. The 3–min cutpoint was considered appropriate because of the relatively slow vessel speed during seismic operations (~4 kt or 7.4 km/h, average). The 1 and 2 h cutoff periods correspond to the time required to transit to an area in which the received sound level would not be likely to have much (if any) effect on the distributions of pinnipeds/polar bears and cetaceans, respectively. The chosen sound levels were comparable to those used in other recent seismic cruises (Holst et al. 2005a,b; Ireland et al. 2005, 2007a,b; Patterson et al. 2007). Observation effort from support vessels was considered seismic if the vessel was within 15 km (9.3 mi; for cetaceans) or 5 km (3.1 mi; for pinnipeds and polar bears) of an active seismic vessel while the guns were firing. The post seismic period for support vessel data was defined as 3 min to 1 h (for pinnipeds and polar bears) or 2 h (for cetaceans) after all seismic activity ceased or the support vessel moved beyond 5 km (3.1 mi; for pinnipeds and polar bears) or 15 km (9.3 mi; for cetaceans) from the active seismic array.

This categorization system was designed primarily to distinguish potential differences in behavior and distribution of marine mammals with and without seismic survey influence. The rate of recovery toward "normal" during the post–seismic period is uncertain. Marine mammal responses to seismic sound likely diminish with time after the cessation of seismic activity. The end of the post–seismic period was defined as a time long enough after cessation of airgun activity to ensure that any carry–over effects of exposure to sounds from the airguns would have waned to zero or near zero. The reasoning behind these categories was explained in MacLean and Koski (2005) and Smultea et al. (2005).

The "post–seismic" category of sightings was excluded when seismic vs. non–seismic sightings were compared. The different definitions of the post–seismic period for cetaceans (3 min to 2 h after cessation of airgun activity) and pinnipeds/polar bears (3 min to 1 h after cessation of airgun activity) resulted in different amount of observer effort being categorized as post–seismic. For simplicity and unless specifically stated otherwise, the results presented in this chapter and Chapter 6 represent the longer period used to define the post–seismic period for cetaceans.

Observer Height Above Water.—Vessels were grouped into two categories, "tall" and "short" based on observer "eye–height" measured from the water surface to the bridge, where observations were usually made. The dividing line between these two categories was identified using ANOVA to determine the presence of a statistical difference in the mean distance of initial detection between the two vessel groups. We used an iterative process where the sightings from a vessel of intermediate height were moved from once category to the other in order of vessel height until the greatest statistically significant difference was identified (F = 296.9, df = 1, *p* <0.0001). The difference in initial detection distance was greatest when the vessels were separated into groups above and below 12 m (39 ft) in observer–eye height as shown in Fig. 3.4.

Grouping vessels in this manner was necessary for calculating *f*(0) correction factors discussed in the *Line Transect Estimation of Densities* section below. Use of these correction factors allowed for calculation of comparable density estimates from vessels of different heights.

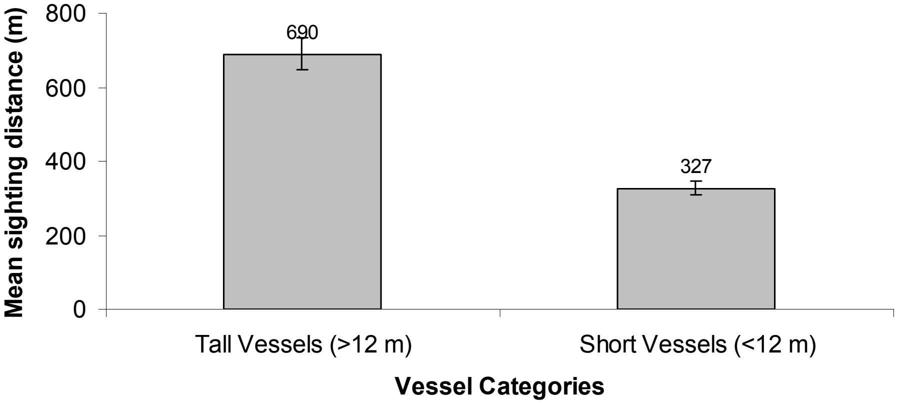

FIGURE 3.4. Mean distance of initial marine mammal sightings recorded on vessels with observation platforms higher and lower than 12 m (39 ft).

Proximity to Shore and Water Depth.—The Chukchi Sea is shallow and relatively uniform in depth (~40–50 m or 131–164 ft) except for the northeast quadrant where one large and several smaller canyons drop toward the Arctic Basin. This made categorization of data by water depth less meaningful than in other locations. In the Chukchi Sea, data collected within 25 km (15.5 mi) of shore were classified as nearshore and those collected greater than 25 km from shore as offshore.

The proximity of the continental shelf break to the Beaufort Sea coast allowed more meaningful use of water–depth data in relation to marine mammal sightings. Effort and sightings in the Beaufort Sea were categorized into three water depth bins: <50 m (<164 ft), 50–200 m (164–656 ft), and >200 m (>656 ft).

Proximity to Ice.—Pinnipeds haul out on ice and often forage near ice. Therefore, pinniped detection rates were expected to be related to the proximity of the vessels to ice. Ice cover and location data for 2006 were obtained from the National Ice Center, NOAA (NIC 2007) and for 2007 from Shell ice forecasts. Data from both sources were derived from a combination of Radarsat, Operational Linescan Systems (OLS), Envisat, Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), and Special Sensor Microwave Imager (SSM/I). The ice edge was defined as the border between <10% ice–cover and 0–5 km (0–3.1 mi) from ice categories. Data collected in the Chukchi and Beaufort seas were categorized into 5–km (3.1 mi) distance–from–ice bins based on the available remote sensing data for the week in which the data were collected. Ice–cover categories included >10% ice cover, <10% ice cover, 0–5 km (0–3.1 mi) from ice, 5–10 km (3.1–6.2 mi) from ice, 10–15 km (6.2–9.3 mi) from ice, 15–20 km (9.3–12.4 mi) from ice, and >20 km (>12.4 mi) from ice. The large difference in ice cover between years in the Chukchi and Beaufort seas may explain some of the between–year difference observed in the vessel–based data (Figs. 3.1 and 6.1).

Initial Behavior and Reaction Data

Marine mammal behavior is difficult to observe, especially from a seismic source vessel, because individuals and/or groups are often at the surface only briefly, and may avoid the vessel. This causes difficulties in re–sighting those animals, and in determining whether two sightings some minutes apart are repeat sightings of the same individual(s). Limited behavioral data were collected during this project because marine mammals were often observed at distances too far from the vessel to determine behavior, and they were typically not tracked for long distances or durations while the vessel was underway.

Data collected during visual observations provided some information about behavioral responses of marine mammals to the seismic survey and related vessel activity, however many of these data are not extensive enough to warrant statistical analysis. Relevant data included:

- bearings and distances of initial sightings of marine mammals from the MMO observation station;
- estimated closest observed points of approach (CPA) of animals relative to either the airgun array (source vessels) or the observer (support vessels);
- animal movements relative to vessel movements;
- observed behavior of animals at the time of the initial sightings; and
- reaction of animals in response to the vessel.

Within each dataset, results were compared between seismic and non–seismic periods.

CPA.—The CPA of each sighting was determined from the data recorded by MMOs. Mean CPA, standard deviation, and range of distances (m) were calculated for useable sightings within each vessel group during seismic and non–seismic periods. Mean CPAs were compared between seismic and non–seismic periods for vessel groups with sufficient sample sizes.

Initial Behavior.—Animal movements and initial observed behaviors between seismic and non–seismic periods were compared. Codes available for MMOs to use in describing initial behavior of marine mammals were different in 2006 and 2007. In 2006 a detailed list of potential marine mammal behaviors was available, but during data analysis specific behaviors were pooled into broader behavioral categories for comparison. Specific behavioral data from 2006 were combined into categories in the following way: front dive, fluke, sink, and thrash became “diving”; look and spy–hop became “looking”; log, raft, and rest became “resting”; surface–active travel, swim, and travel became “swim”; blow, breach, bow–riding, flipper–slap, lob–tail, mill, porpoise, surface active, and wake–riding became “surface active”; individual and group feeding became “feeding”. Note that blow falls under the “surface active” category, and for large whales in particular, blows are a very common sighting cue. Therefore, most sightings coded “surface active” do not imply splashing behavior. The broader categories were used in 2007 as the codes available to MMOs for describing marine mammal behavior and included feeding, resting, surface active, looking, diving, swimming, walking, other, or unknown.

Reaction Behavior.—A specific format for noting reaction behaviors was added to data recording protocols in 2007. Available codes included, splash, increase in speed, decrease in speed, change in direction, bow riding or wake riding, interactions with gear, looking, and rushing (i.e., by hauled out animals). In 2006 and years prior, potential reactions to the vessel were summarized and interpreted in the text of reports from movement, behavior, and pace data. A set of conversion rules was created to use movement and pace codes from 2006 data to systematically create a set of reaction codes in the 2006 data consistent with 2007 reactions codes (Table 3.2).

TABLE 3.2. Movement, Behavior and Pace code combinations used to generate equivalent 2007 Reactions codes in the 2006 data.

2006		2007
Movement or Behavior	**Pace**	**Reaction**
Movement		
Dead	any	None
Flee	any	Increase speed
Hauled out	any	None
Mill	any	None
No	any	None
Perpendicular	SE	None
Perpendicular	MO	None
Perpendicular	VI	Increase speed
Swim Away	SE	None
Swim Away	MO	Change direction
Swim Away	VI	Change direction
Swim parallel	SE	None
Swim parallel	MO	None
Swim parallel	VI	Increase speed
Swim Towards	SE	None
Swim Towards	MO	Change direction
Swim Towards	VI	Change direction
Unknown	any	None
Behavior		
Breach	any	Splash
Flipper slap	any	Splash
Look	any	Look
Lob-tail	any	Splash
Porpoise	any	None
Spy-hop	any	Look
Thrash dive	any	Splash
Bow Riding	any	Bow or wake riding
Wake Riding	any	Bow or wake riding

Line Transect Estimation of Densities

The most appropriate criteria for "take by harassment" are uncertain and presumably vary among species and situations. Furthermore, obtaining meaningful estimates of the number of marine mammals exposed to various levels of seismic sounds is difficult for multiple reasons:

- The relationship between numbers of marine mammals that are observed and the number actually present is uncertain.
- The distances to which a received sound level exceeds a specific criterion such as 190 dB, 180 dB, 170 dB, or 160 dB re 1 µPa (rms) vary. Variables governing this relationship include source depth, water mass and bottom conditions, and—for directional sources—aspect (Greene 1997; Greene et. al. 1998; Burgess and Greene 1999; Caldwell and Dragoset 2000; Tolstoy et al. 2004a,b).
- The sounds received by marine mammals vary depending on their depth in the water, and are considerably reduced for animals at or near the surface (Greene and Richardson 1988; Tolstoy et al. 2004a,b) and further reduced for animals on ice.

Raw sighting data obtained from marine mammal surveys provide, at best, an index of the minimum number of animals possibly present at the time of the survey (Eberhardt et al. 1979; Best 1982; Hiby and Hammond 1989). Some animals that are present, and theoretically could be seen by observers, are not detected because of glare, haze, fog, sea conditions, ice cover, behavior of the target species, observer fatigue, abilities of the observer, obstructions to the viewing area and other factors (Holt 1987; Marsh and Sinclair 1989; DeMaster et al. 2001; Barlow et al. 2006). The proportion of animals missed due to the above factors varies depending on the severity of those factors and is specific to a particular survey. For example, Barlow et al. (2006) showed that encounter rates for small beaked whales (genera *Mesoplodon* and *Ziphius*), which are especially difficult to sight, were about 10–30× higher during Beaufort wind force 0 and 1 than during Beaufort wind force 4 and 5. Further complicating the estimation of densities or numbers of marine mammals present during a survey is the fact that most marine mammals dive below the surface, and therefore are out of sight for extended periods (Leatherwood et al. 1982; Martin et al. 1993; Barlow 1999; Thomas et al. 2002). The proportion of time that marine mammals are at the surface depends on their species, activity, season, weather and other factors.

Line transect methodology (Buckland et al. 1993), often implemented using the Distance program (Thomas et al. 2006, version 5.0, release 2), is the most commonly used method for estimating densities of animals from transect survey data. In theory, two correction factors, $f(0)$ and $g(0)$, can be computed from the raw survey data or from other observations to minimize most biases in estimates of actual numbers of marine mammals present.

Parameter $f(0)$ accounts for the reduced probability of detecting an animal as its distance from the trackline increases. It is assumed that all animals directly on the trackline are seen or, if not seen, are accounted for by parameter $g(0)$.

Parameter $g(0)$ accounts for animals on the trackline that are not detected during the survey. In most surveys, $g(0)$ accounts for animals at the surface and available to be seen but, in fact, are not seen by the primary observer; this is “detectability bias,” $g_d(0)$, otherwise known as “perception bias.” In some cases, $g(0)$ has been calculated to account for the fact that marine mammals are often below the surface as the survey aircraft or vessel passes; this is “availability bias” $g_a(0)$. Corrections for availability bias account for the probability that an animal on the trackline will be at the surface while the surveyors are close enough to detect the animal. Failure to account for availability bias can cause significant underestimates, particularly for species that dive for long periods like bowhead whales, and/or when a rapidly–moving survey platform (such as an aircraft) is used. When there are estimates for both $g_d(0)$ and $g_a(0)$, then $g(0)$ is the product of these two estimates.

Densities were calculated separately for each species or species group using only useable data within the following categories:

- location (Chukchi Sea, Beaufort Sea)
- season (Jun–Aug; Sep–Nov);
- seismic state (seismic, non–seismic); and
- vessel group (tall source vessel, tall support vessels, and short support vessels).

Grouping of vessels into “tall” and “short” categories (described above in *Observer Height Above Water*) was necessary because $f(0)$ correction values differ significantly for data collected at different heights above water.

Line transect methods (Buckland et al. 1993) were used to estimate densities using the equation:

$$D = \frac{n \times S \times f(0)}{2 \times L \times g(0)}$$

where D = density of a species in number of animals/km^2,

n = number of sightings,

S = mean group size,

$f(0)$ = sighting probability density on the trackline,

L = length of trackline completed (in km),

$g(0)$ = probability of seeing a group directly on the trackline.

Densities from different vessel groups within the same season and location (i.e. Chukchi Sea, summer, non–seismic) were combined by using effort to calculate a weighted average. Densities were not calculated for categories where less than 500 km (311 mi) of useable survey effort were obtained. For those categories, the densities used when estimating the number of animals potentially affected by seismic activities were selected from categories with the most similar geographic, habitat, and seasonal characteristics. For more details on the calculations of $f(0)$, $g(0)$, and densities, including an example calculation, see Appendix F.

Densities estimated from non–seismic periods were used to estimate the numbers of animals that presumably would have been present in the absence of seismic activities. Densities during seismic periods were used to estimate the numbers of animals present near the seismic operation and exposed to various sound levels. The difference between the two estimates could be taken as an estimate of the number of animals that moved in response to the operating seismic vessel, or that changed their behavior sufficiently to affect their detectability by visual observers.

Estimating Number of Marine Mammals Potentially Affected

160 dB Criteria.—NMFS practice in situations with intermittent impulsive sounds like seismic has been to assume that "take by harassment" (Level B) may occur if baleen whales are exposed to received levels of sounds exceeding 160 dB re 1 µPa rms (NMFS 2005, 2006). The reaction threshold for most toothed whales is unknown but presumably higher because of their poorer hearing sensitivity at low frequencies (NMFS 2005; NMFS 2006; Richardson et al. 1995; Richardson and Würsig 1997). However, the limited empirical data for beluga whales indicate that they may be relatively responsive to airgun sounds as compared with other toothed whales (Miller et al. 2005). When calculating the number of mammals potentially affected, we used the measured 160 dB radii (Tables 3.1 and 6.1).

Three methods were used to estimate the number of pinnipeds and cetaceans exposed to airgun sound levels that might have caused disturbance or other effects. The methods were:

(A) minimum estimates based on direct observations;

(B) estimates based on pinniped and cetacean densities derived from observations made during seismic periods; and

(C) maximum estimates based on pinniped and cetacean densities derived from observations made during non–seismic periods.

The actual number of individuals exposed to, and potentially affected by, seismic survey sounds was likely between these minimum and maximum estimates resulting from methods ***(A)*** and ***(C)***. Calculation of densities and the correction factors used to compute densities are described in *Line Transect Estimation of Densities* above and in Appendix F

Method ***(C)*** above provides an estimate of the number of animals that would have been exposed to airgun sounds at various levels if the seismic activities did not influence the distribution of animals near the activities. However, it is known that some animals are likely to have avoided the area near the seismic vessel while the airguns were firing (see Richardson et al. 1995, 1999; Stone 2003; Gordon et al. 2004; Smultea et al. 2004). Within at least the 160–170 dB radii around the source (i.e., ~4.5–13.4 km or ~2.8–8.3 mi), the distribution and behavior of cetaceans may have been altered as a result of the seismic survey. The distribution and behavior of pinnipeds may have been altered within some lesser distance. These effects could occur because of reactions to the active airgun array, or to other sound sources or other vessels working in the area. Thus method ***(B)*** may provide a more realistic estimate of the number of animals exposed to the higher sound levels of interest.

We used data from both source vessels and support vessels to investigate how far from the source vessel behavioral reactions extended. During past studies, data were typically available from only the source vessel. Here, as a refinement to method ***(B)***, we have calculated densities of marine mammals separately using data collected on the source vessel and on the support vessel when it was >1.0 km (0.6 mi; pinnipeds) or >5.0 km (3.1 mi; cetaceans) from the source vessel during seismic periods. During seismic periods in 2006, support vessels typically operated approximately 6 km (3.7 mi) from the source vessels. In 2007 support vessels were typically 1–3 km (0.6–1.8 mi) ahead of the source vessel because SOI voluntarily used additional support vessels to monitor the ≥180 dB safety zone. MMOs noted times when support vessels were required to be farther away from source vessels (*e.g.* when scouting for ice).

The aforementioned densities were used to estimate the number of animals potentially affected by seismic operations (methods ***(B)*** and ***(C)***). This involved using two approaches to estimate the extent to which marine mammals may have been exposed to given sound levels ≥160, ≥170, ≥180, and ≥190 dB (rms):

1. Estimates of the number of different *individual* marine mammals exposed; and
2. Estimates of the average number of *exposures* each individual received.

For each source vessel we used the same 160, 170, 180, and 190 dB (rms) distances that were used in the separate 90–day reports (see Table 3.1). The following description of the two different methods refers only to the ≥160 dB re 1 µPa (rms) sound level, but the same method of calculation was used for ≥170, ≥180, and ≥190 dB (rms).

The first method ("individuals") involved multiplying the following three values for each airgun configuration in use and within each season:

- km of seismic survey;
- width of area assumed to be ensonified to ≥160 dB (2 × 160 dB radius), with areas ensonified on more than one occasion counted only once; and
- densities of marine mammals estimated from this study.

Counting areas of water ensonified more than one time (due to overlapping or adjacent tracklines) only once may underestimate the number of different animals exposed. This is likely to occur when the activities are conducted over a long period, as individual animals may move in and out of the ensonified area. The individuals present when an area is ensonified a second or subsequent time are not necessarily the same animals as were present when the area was first ensonified.

The second approach ("exposures") involved multiplying the same three values, except that areas ensonified to ≥160 dB on more than one occasion, due to overlapping or closely spaced tracklines, were counted as many times as they were ensonified. The area of water considered ensonified in this calculation was therefore larger than in the first calculation. During the Chukchi Sea surveys, many of the tracklines were sufficiently close to one another (e.g. 200 to 300 m (219 to 328 yd) for there to be overlap between the ensonified areas around different lines. When there was substantial overlap, the two approaches led to very different values for the ensonified area, and the estimated number of exposures was much higher than the estimated number of individuals exposed.

Finally, the number of exposures was divided by the estimated number of individuals exposed to calculate the average number of exposures per individual. This calculation assumed that individuals did not show avoidance reactions, which could be true for some species.

This approach was originally developed to estimate the number of seals potentially affected by seismic surveys in the Alaskan Beaufort Sea conducted under IHAs (Harris et al. 2001). The approach has recently been used in estimating the numbers of seals and cetaceans potentially affected by other seismic surveys conducted under IHAs in the Arctic and elsewhere (e.g., Haley and Koski 2004; Smultea et al. 2004, 2005; MacLean and Koski 2005; Holst et al. 2005a,b; Ireland et al. 2007a,b; Patterson et al. 2007).

The estimates provided here are based on the actual number of km of seismic survey completed during all project activities. In contrast, the estimates provided in the 90–day reports did not consider that there may have been overlap in areas surveyed. The estimates provided here use the combined data from all surveys to compute correction factors that account for biases associated with different numbers of observers, habitats, and seasons.

RESULTS

Survey Effort

This section summarizes the visual monitoring effort from the various seismic survey vessels and support vessels that operated within the Chukchi Sea in 2006 and 2007. The data were reported according to the categories defined in the *Methods* section above. During 2006 Chukchi Sea survey operations, 105,764 km (~65,719 mi) of trackline were covered; 47,024 km (29,219 mi) of trackline were covered in 2007. The combined total for both 2006 and 2007 was 152,788 km (94,938 mi) of trackline.

Visual observations by MMOs were conducted over 74,257 km (46,141 mi; 6972 h) of trackline in 2006 and 29,127 km (18,099 mi; 2577 h) in 2007 for a total of 103,384 km (~64,239 mi; 9,549 h). The amount of MMO watch effort from source and support vessels combined in 25 km^2 blocks in the Chukchi Sea project area is shown on Fig. 3.5. Actual amounts of useable effort were different for cetaceans, pinnipeds, and ursids, due to the different definitions of unusable "post–seismic" period and vessel proximity criteria for each group (see *Usability Criteria* in *Methods*). Based on these usability criteria, 29,182–36,090 km (18,133–22,425 mi; 2484–3068 h) of trackline, or 39–47% of the 2006 visual effort, was considered "useable". Of the 2007 observer data, 43–54% or 12,714–15,814 km (7900–9826 mi; 850–1152 h) was considered useable. Ranges of useable effort presented here are for all species groups; effort will be limited to observer effort for cetaceans from this point forward.

Average visibility in 2006 during daytime periods was 7.6 km (4.7 mi; *n* = 22,538 records where visibility value were entered), and average Beaufort wind force (Bf) was Bf 3.8 (*n* = 24,059 wind force records). Average visibility in 2007 during daytime periods was 6.3 km (3.9 mi; *n* = 10,669 visibility records), and average Beaufort wind force was Bf 3.4 (*n* = 11,173 wind force records). The percent of seasonal effort was categorized by Beaufort wind force in Fig. 3.6 and Appendix Tables A.1–4 (including effort in mi and h). In general, Beaufort wind force was higher in Sep–Oct than in Jul–Aug (Fig. 3.6). The majority of useable observation effort was conducted in Bf 2–4 (Fig. 3.6). There were negligible amounts of useable effort during Bf zero in both 2006 and 2007 (Fig. 3.56).

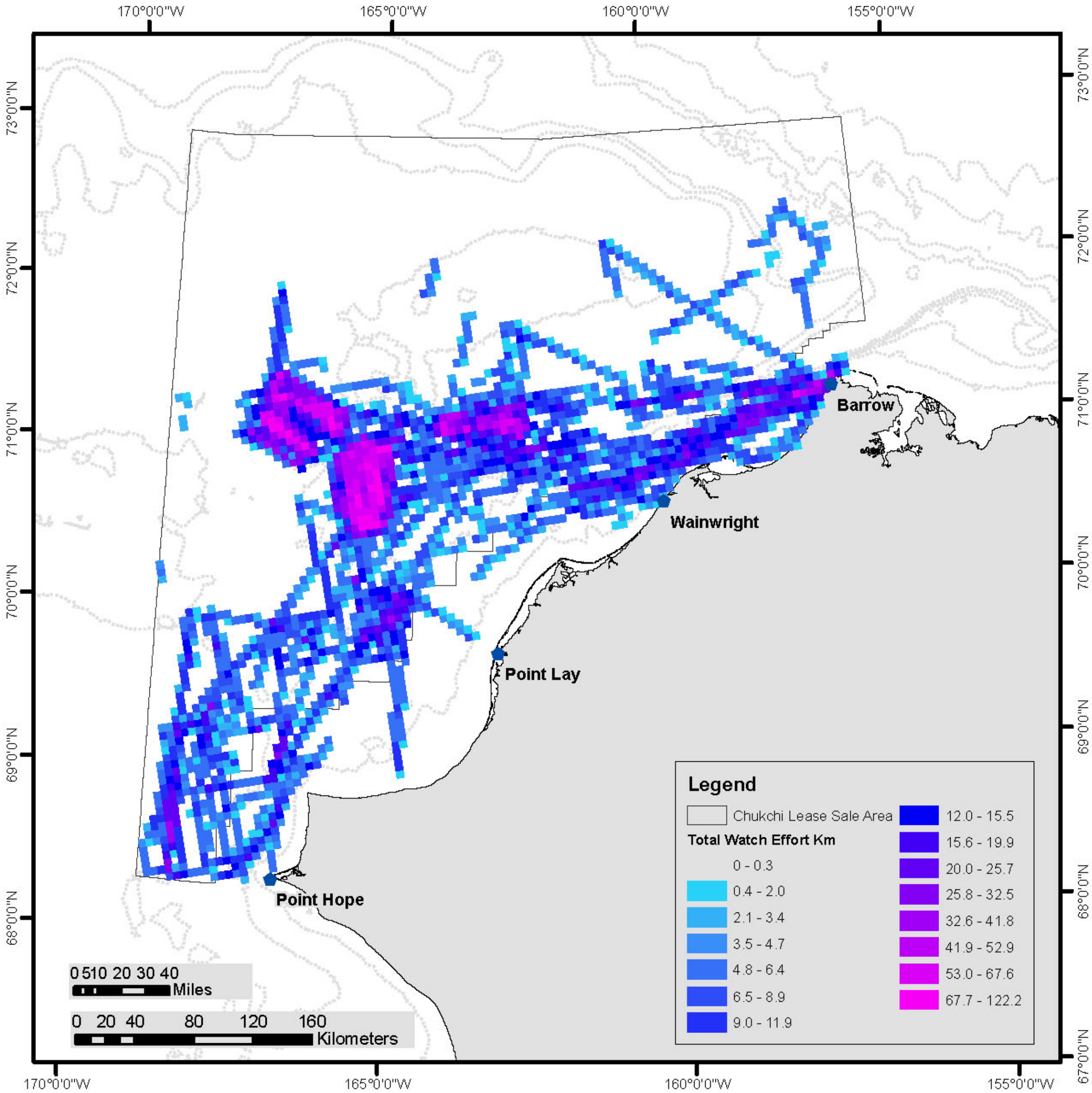

FIGURE 3.5. Total kilometers of useable MMO watch effort in 25 km^2 blocks during source and support vessel operations related to offshore seismic exploration activities in the Chukchi Sea in 2006 and 2007.

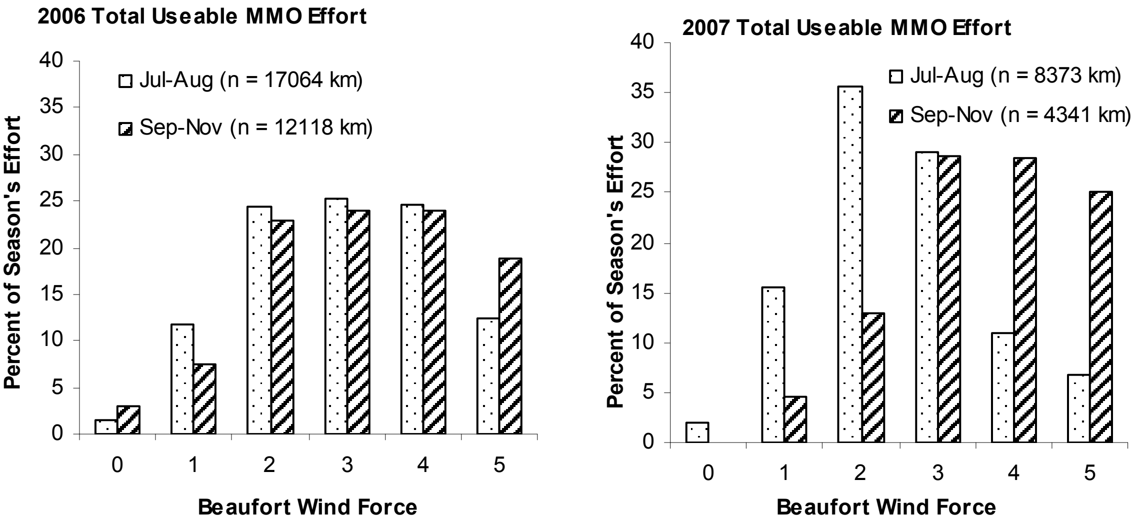

FIGURE 3.6. Percent of total useable marine mammal observer effort in summer (Jul–Aug) and fall (Sep–Oct) from all vessels in the Chukchi Sea study area, by wind force in 2006 and 2007. Note that effort was different for cetaceans, pinnipeds, and ursids (polar bear) due to differences in usability definitions; data presented here are for cetaceans. For effort in hours, see Appendix Tables A.1–2.

Source Vessels.—This data set combined the tracklines from the source vessels *Gilavar*, *Patriot*, and *Discoverer* from the 2006 survey seasons for a total of 7963 km (4947 mi; ~887 h; Fig. 3.7; Appendix Table A.1–4) of 2006 useable visual observations. The *Gilavar* was the single operating source vessel in the Chukchi Sea in 2007. MMOs collected 1291 km (802 mi; 139 h; Figs. 3.6 and 3.7; Appendix Table A.1–4) of useable effort in the Chukchi Sea in 2007 from the *Gilavar*.

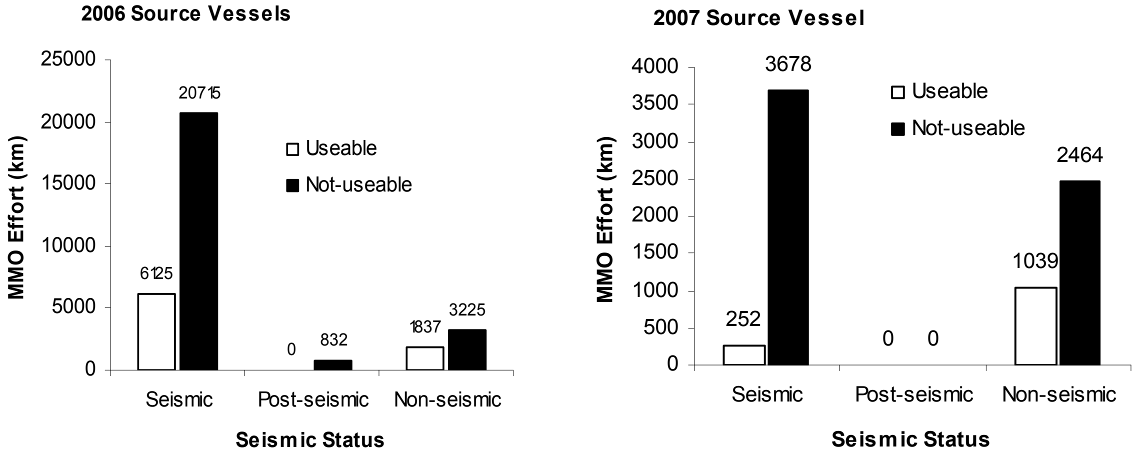

FIGURE 3.7. Visual observation effort, in kilometers, from the source vessels within the Chukchi Sea. For effort in miles and hours, see Appendix Tables A.1–2.

The majority of useable effort from source vessels was conducted during the summer months (Jul–Aug) when sea conditions were generally calmer (Fig. 3.8). Approximately 74% of useable MMO effort occurred in the summer.

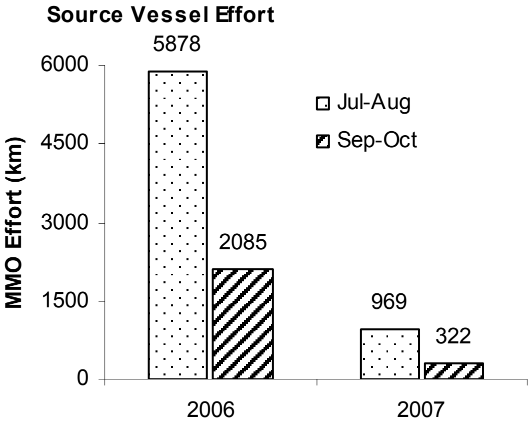

FIGURE 3.8. Useable visual observation effort in kilometers for source vessels during Jul–Aug vs. Sep–Oct. For effort in miles and hours, see Appendix Tables A.1–2.

More than 99% of all of the 2006 useable effort on the source vessels (6123 km [3805 mi] seismic and 1797 km [1117 mi] non–seismic) was conducted in the offshore region as opposed to the nearshore region (Fig. 3.9). All 1291 km (802 mi) of useable effort from the *Gilavar* in 2007 was offshore (252 km [157 mi] seismic and 1039 km [646 mi] non–seismic). Very little monitoring occurred in the nearshore waters of the Chukchi Sea from the source vessels; only 43 km (27 mi) of effort was recorded in 2006 and none in 2007 (Fig.3.9).

In offshore areas, most visual observations from source vessels were conducted by one MMO at a time (~66% of seismic effort, ~76% of non–seismic effort in 2006; ~61% seismic effort, 51% non–seismic effort in 2007; Fig.3.9). Two MMOs were on duty offshore for ~33% of the useable seismic effort and 24% of the useable non–seismic effort from the source vessels in 2006. In 2007, two MMOs were on watch for ~37% of useable effort during seismic periods and for 49% of the useable effort during non–seismic periods (Fig.3.9). Periods with three MMOs on watch accounted for less than 1% of the effort during seismic periods in 2006 and less than 2% of the effort during 2007. Three MMOs were not on watch simultaneously during non–seismic periods on the source vessels either year (Fig.3.9).

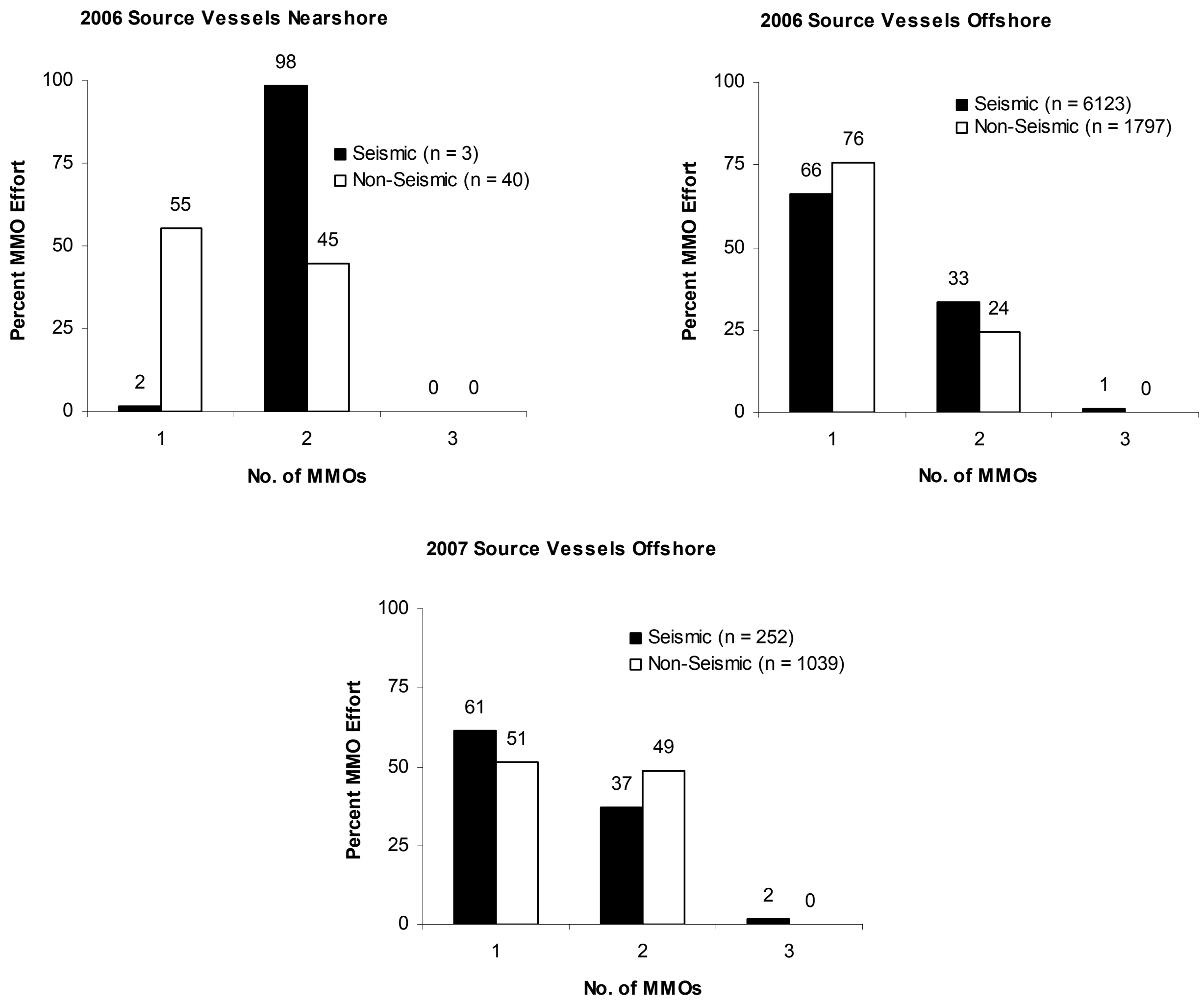

FIGURE 3.9. Percent of useable effort by number of MMOs monitoring from source vessels in nearshore and offshore areas of the Chukchi Sea, 2006 and 2007. *n* = the total number of useable km of effort.

Of the 5101 km (3170 mi; 565 h) of effort conducted during periods of darkness in 2006, the majority occurred during seismic periods (95% or 4835 km [3004 mi]). Most 2006 nighttime observation effort occurred on source vessels (~93% or ~4724 km [2935 mi]), with the remaining nighttime effort conducted from the support vessels. Similarly, most 2007 nighttime observer effort occurred during seismic periods (67% or 1002 km [623 mi] of 1504 km [935 mi] total effort in darkness) and 66% of nighttime effort (1001 km [622 mi]) was conducted from source vessels. During periods of darkness there were two marine mammal observations from the source vessels recorded for 2006 and 2007 combined; each of these observations was of a Pacific walrus sighted within 300 m of the vessel during the 2007 season. The two nighttime observations were recorded from the source vessel when it was not conducting seismic operations.

Support Vessels.—Chukchi Sea support vessel data consisted of the pooled useable, visual observation data from the support vessels *Kilabuk, Torsvik, Octopus, Tor Viking, Norseman, Nanuq, American Islander, Fennica, Kapitan Dranitsyn* and *Gulf Provider*. MMOs were on watch for a total of 41,522 km

(25,801 mi) of trackline in 2006. Fifty–one percent of that effort was considered useable (Fig 3.10). Similarly, in 2007 ~53% of observer effort (11,423 km or 7098 mi) from the support vessels was categorized as useable (Fig 3.10). There was relatively little useable MMO effort on the support vessels during seismic periods in 2007 (Fig. 3.10).

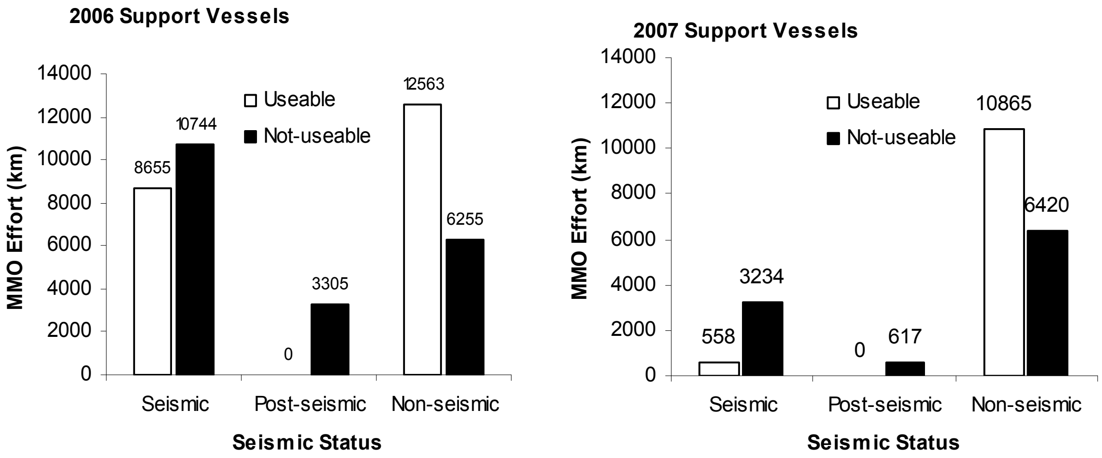

FIGURE 3.10. Visual observation effort in kilometers from support vessels in the Chukchi Sea, 2006 and 2007. For effort in miles and hours, see Appendix Tables A.1–2.

The majority of the useable effort from the support vessels occurred in the summer months, as was the case for observation effort from the source vessels. Approximately 60% of useable effort from the support vessels was conducted in Jul and Aug (Fig.3.11).

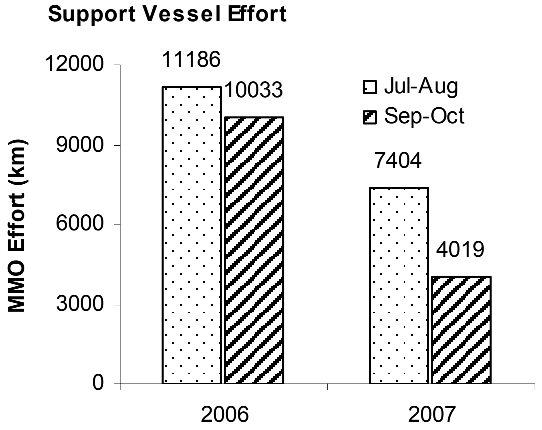

FIGURE 3.11. Useable visual observation effort in kilometers for support vessels during Jul–Aug vs. Sep–Oct. For effort in miles and hours, see Appendix Tables A.1–2.

There was less than one percent of useable effort from support vessels in the nearshore region in 2006 during seismic periods (119 km or 74 mi.; i.e., when in nearshore waters, these vessels seldom came within 15 km [~9mi] of an operating seismic vessel) and none in 2007. Most useable non–seismic effort was conducted in the offshore region (~66% in 2006 and 78% in 2007). In the offshore area, useable non–seismic effort was greater than useable seismic effort (10,665 km [6627 mi] vs. 8536 km [5304 mi] in 2006 and 9984 km [6204] vs. 558 km [347 mi] in 2007).

On the support vessels in 2006, one MMO was on watch during all useable nearshore seismic effort and during 50% of the nearshore non–seismic effort (Fig. 3.9). Two and three MMOs were on watch for 27 and 23% of the nearshore non–seismic effort, respectively.

A single MMO was on watch for 85% of the useable seismic effort offshore and 63% of the useable non–seismic effort offshore on support vessels in 2006 (Fig. 3.9). No useable seismic effort was recorded from support vessels in the nearshore area in 2007. Most of the effort in the nearshore area (86%) was conducted with one MMO on watch. Two and three MMOs were on watch for only 12 and 2% of the effort, respectively.

In the offshore area in 2007, one MMO was on watch during most of the seismic (90%) and non–seismic (85%) effort. Two MMOs were on watch for only 10% of the offshore seismic effort and 15% of the non–seismic effort. Almost no effort was conducted with three MMOs on watch in 2007.

Visual Sightings of Marine Mammals

Total Sightings.—The analyses here and in the sections below for cetaceans, pinnipeds, and Pacific walrus are based primarily on useable data as described in the *Methods* section. In some cases we use all data regardless of usability criteria for comparison of the results. In general, use of all sightings and all effort decreases the power of the data set to determine differences in the results. The numbers of marine mammal sightings regardless of usability criteria for source and support vessels during 2006 and 2007 are listed in Appendix Table A.5. This section discusses numbers of detections and detection rates by season and seismic state for all marine mammal species in general. These same topics are discussed for specific marine mammal groups in the sections below.

There were 1935 marine mammal detections (a detection is a sighting of an individual or group of marine mammals) consisting of an estimated 3162 individuals in the Chukchi Sea during 2006 vessel operations compared with only 630 useable marine mammal sightings of an estimated 3403 individuals in 2007 (Table 3.3). A substantial portion of the total sightings and individual marine mammals in 2007 was recorded on 24 Aug (UTC) from the Gilavar when MMOs documented 143 sightings of Pacific walruses consisting of 1050 animals (~23% of useable sightings and 31% of individuals for the entire 2007 Chukchi season; this 24 Aug Pacific walrus sightings event is discussed below in the section on *Pacific walruses*).

The total number of marine mammal sightings in 2007 (630) was ~3 times less than the number reported in 2006 (1935). The greater number of sightings in 2006 was likely related to the greater amount of useable effort in 2006 compared to 2007 for both cetaceans and pinnipeds (Appendix Tables A.1 and A.2). Although effort and sightings were greater in 2006, more individual marine mammals were recorded in 2007 (3403) compared to 2006 (3162). Much of difference resulted from large groups of Pacific walruses observed in 2007 totaling 2955 animals (Table 3.3). In 2007 Pacific walruses comprised ~87% of the total number of individual marine mammals recorded compared to ~35% in 2006. Differences in the numbers of walrus sightings and individuals between 2006 and 2007 are discussed below in the *Pacific walrus* section. Detection rates of marine mammals by season and seismic state are discussed directly below. All Chukchi Sea marine mammal sightings for 2006 and 2007 are summarized in Appendix Table A.5.

More seal individuals were recorded in 2006 (1933) than in 2007 (338; Table 3.3). The ringed/spotted seal category in 2006 was comprised of 35% ringed seals, 11% spotted seals, and 54%

unidentified seals. In 2007 the breakdown was 36% ringed seals, 9% spotted seals, and 55% unidentified seals. Although more cetaceans were recorded in 2006 (130) than in 2007 (110), the difference was less dramatic. Five polar bear sightings were recorded in 2006 but no useable polar bear sightings were reported for 2007.

TABLE 3.3. All useable marine mammal sightings (number of individuals) recorded by MMOs in the Chukchi Sea during 2006 and 2007 Chukchi Sea vessel operations.

Species	**Source Vessels**		**Support Vessels**		**Annual Totals**	
	2006	**2007**	**2006**	**2007**	**2006**	**2007**
Cetaceans						
Unidentified Whale	1 (2)	1 (1)	11 (13)	2 (2)	***12 (15)***	***3 (3)***
Mysticetes						
Bowhead Whale	3 (3)	3 (4)	22 (41)	3 (3)	***25 (44)***	***6 (7)***
Minke Whale	2 (2)	0	1 (1)	3 (3)	***3 (3)***	***3 (3)***
Gray Whale	0	2 (2)	23 (43)	30 (64)	***23 (43)***	***32 (66)***
Humpback Whale	0	0	0	2 (3)	***0***	***2 (3)***
Unidentified Mysticete Whale	2 (2)	0	1 (1)	6 (10)	***3 (3)***	***6 (10)***
Odontocetes						
Killer Whale	0	1 (1)	1 (2)	0	***1 (2)***	***1 (1)***
Harbor Porpoise	3 (5)	3 (4)	6 (11)	7 (12)	***9 (16)***	***10 (16)***
Unidentified Dolphin	0	0	3 (4)	0	***3 (4)***	***0***
Unidentified Odontocete Whale	0	0	0	1 (1)	***0***	***1 (1)***
Total Cetaceans	***11 (14)***	***10 (12)***	***68 (116)***	***54 (98)***	***79 (130)***	***64 (110)***
Seals and Sea Lions						
Bearded Seal	11 (16)	1 (1)	205 (241)	36 (53)	***216 (257)***	***37 (54)***
Ringed and Spotted Seals[a]	153 (161)	10 (10)	1333 (1492)	170 (255)	***1486 (1653)***	***180 (265)***
Steller Sea Lion	0	0	0	1 (1)	***0***	***1 (1)***
Ribbon Seal	1 (1)	0	0	0	***1 (1)***	***0***
Unidentified Pinnipeds	13 (14)	3 (4)	8 (8)	11 (14)	***21 (22)***	***14 (18)***
Total Seals and Sea Lions	***178 (192)***	***14 (15)***	***1546 (1741)***	***218 (323)***	***1724 (1933)***	***232 (338)***
Pacific Walruses	***24 (40)***	***207 (1559)***	***103 (1054)***	***127 (1396)***	***127 (1094)***	***334 (2955)***
Polar Bears	***0***	***0***	***5 (5)***	***0***	***5 (5)***	***0***
Grand Total of All Sightings	***213 (246)***	***231 (1586)***	***1722 (2916)***	***399 (1817)***	***1935 (3162)***	***630 (3403)***

[a] Includes all records of ringed, spotted, and unidentified seals.

Total Sightings by Season.—More marine mammal sightings were recorded from support than source vessels for 2006 and 2007 combined (Table 3.3; Fig. 3.12). The number of marine mammal sightings from source vessels was slightly greater than for support vessels during summer (Jul–Aug) 2007 (Fig. 3.12). For all other seasonal comparisons between source and support vessels in 2007 and 2006, the numbers of marine mammal sightings were greater from support than source vessels. The number of sightings from support vessel ranged from ~4 to 24 times greater than from source vessels when comparing fall 2007 and summer and fall 2006. The greatest difference in the number of sightings between the two vessel types occurred during fall 2006. The larger percentage of marine mammal sightings recorded from source vessels in summer 2007 compared to fall 2007 and both seasons in 2006 was due to the large number of Pacific walrus sightings on 24 Aug (143) which accounted for ~68% of the 2007 summer sightings from the source vessel (210; Fig. 3.12).

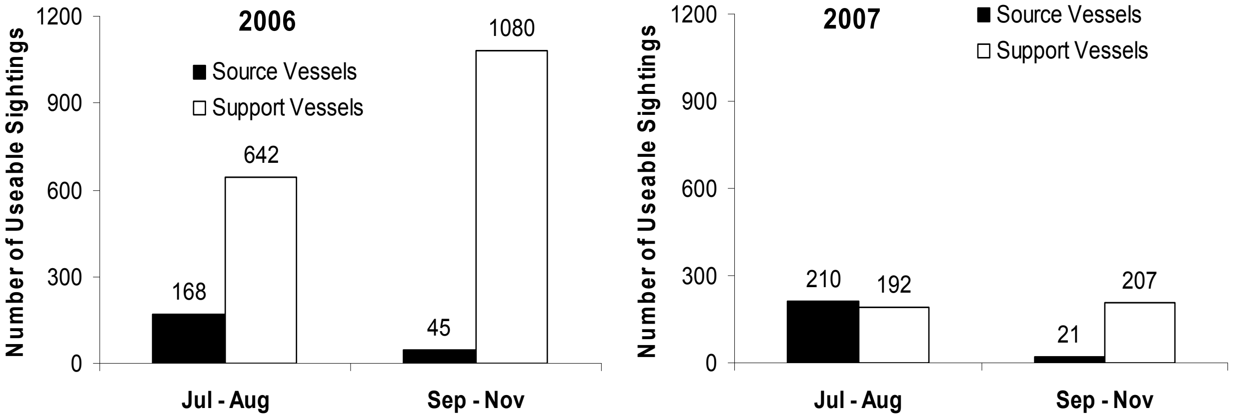

FIGURE 3.12. Total useable marine mammal sightings from source and support vessels by season during 2006 and 2007 Chukchi Sea vessel operations.

Detection Rates by Season.—Marine mammal detection rates by season and year were generally greater from support than source vessels (Fig. 3.13). The exception was summer 2007 when the marine mammal detection rate from the source vessel (*Gilivar*) was far greater than from support vessels. This difference was due to the large number of Pacific walrus sightings on 24 Aug, all of which were recorded by MMOs on the *Gilivar*.

Summer and fall marine mammal detection rates from support vessels were lower in 2007 than 2006. Marine mammal detection rates from source vessels were generally similar for 2006 and 2007 with the exception of the increased detection rate in summer 2007 which was due to the 24 Aug Pacific walrus sighting event.

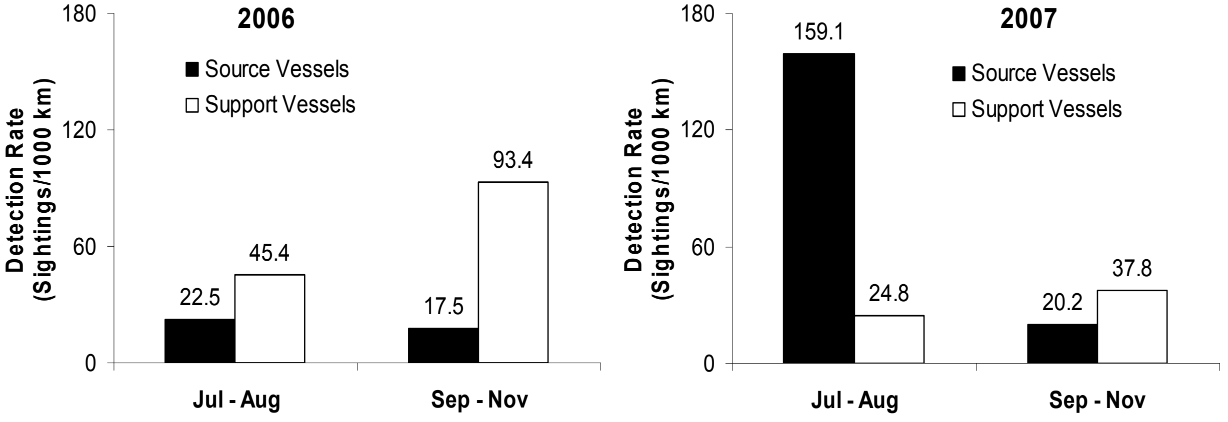

FIGURE 3.13. Detection rates of marine mammals by season during useable periods of 2006 and 2007 Chukchi Sea vessel operations.

Total Sightings by Seismic State.—More marine mammal sightings were recorded from support than source vessels during both seismic and non–seismic periods in 2006 and 2007 (Fig. 3.14). The greatest difference in the number of sightings between source and support vessels occurred during non–seismic periods in 2006 when the number of marine mammal sightings from support vessels was nearly

17 times greater than from source vessels. For all other comparisons the differences in numbers of marine mammal sighting between source and support vessels was much less. The low numbers of sightings during seismic periods in 2007 from both source and support vessels were due in part to the low amount of useable seismic data in 2007. See Appendix Table A.6 for a breakdown of sightings by seismic state.

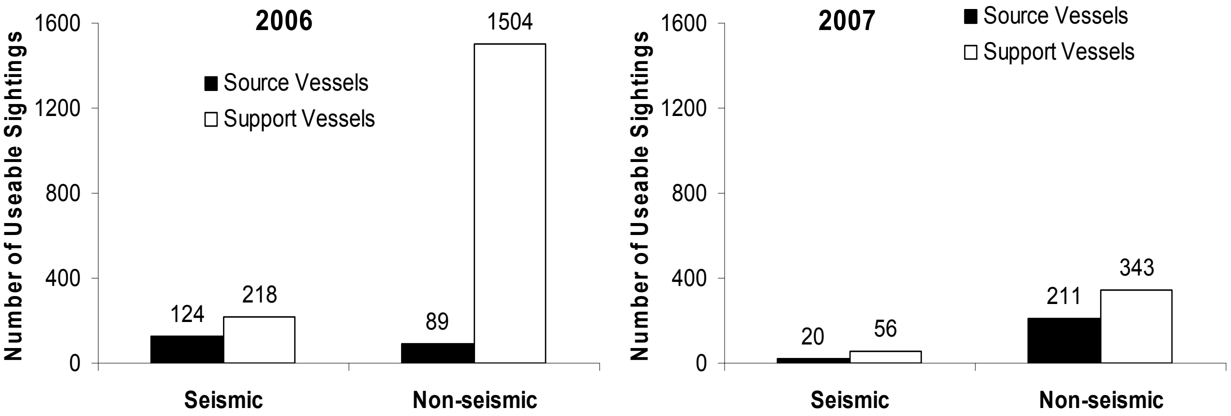

FIGURE 3.14. Total useable marine mammal sightings by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations.

Detection Rates by Seismic State.—Detection rates of marine mammals were higher from support vessels than from source vessels for both seismic and non–seismic periods during 2006 Chukchi Sea vessel operations (Fig. 3.15). Marine mammal detection rates from source and support vessels during seismic and non–seismic periods in 2007 generally fell into ranges similar to those reported in 2006 with the exception of the source vessel detection rate during non–seismic periods (Fig. 3.15). The non–seismic detection rate from the source vessel in 2007 was nearly five times greater than the non–seismic rate from support vessels in 2007. This was primarily due to the high numbers of Pacific walruses recorded from the *Gilavar* on 24 Aug before seismic surveys began.

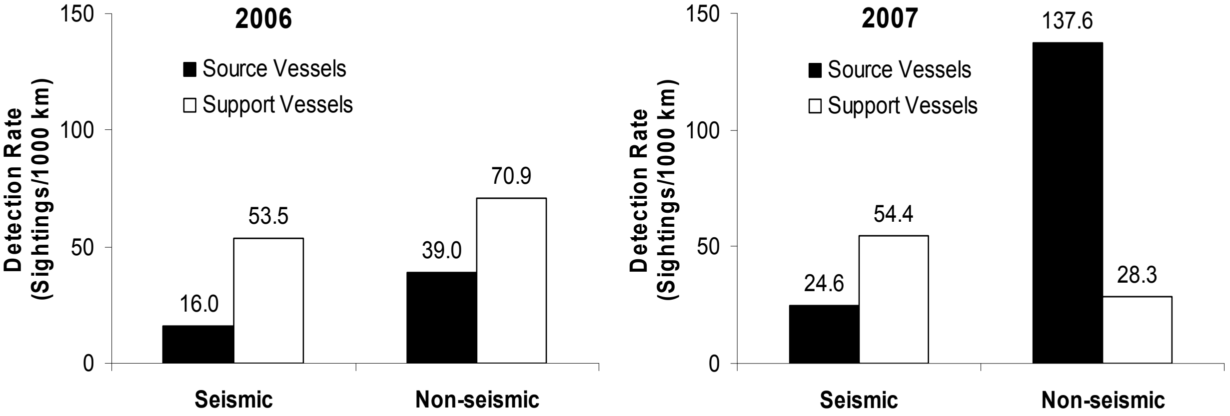

FIGURE 3.15. Detection rates of marine mammals by seismic state during useable periods of 2006 and 2007 Chukchi Sea vessel operations.

Cetaceans

Sightings

Total Sightings.—In 2006, MMOs recorded a total of 79 useable cetacean sightings of 130 individuals in the Chukchi Sea (Table 3.4). Bowhead and gray whales were seen most often (25 and 23 sightings, respectively), followed by unidentified whales (12 sightings), harbor porpoises (nine sightings), minke whales (three sightings), unidentified mysticete whales (three sightings), unidentified dolphins (three sightings), and one killer whale (Table 3.4). The total numbers of sightings for each cetacean species regardless of usability criteria are shown in Appendix Table A.5.

There was a total of 64 useable cetacean sightings comprised of an estimated 110 individuals observed by MMOs within the Chukchi Sea in 2007 (Table 3.4). The most commonly recorded cetacean species in 2007 was gray whale (32 sightings), followed by harbor porpoise (10 sightings), bowhead whale (six sightings), unidentified mysticete whale (six sightings), unidentified whale (three sightings), minke whale (three sightings), humpback whale (two sightings), killer whale (one sighting) and unidentified odontocete whale (one sighting; Table 3.4).

The species composition of cetacean sightings in 2007 was similar to that observed in 2006 with approximately 90% of useable observations in each year consisting of bowhead whales, gray whales, harbor porpoises, unidentified mysticete whales and unidentified whales. The largest difference between years was in the percent composition of gray and bowhead whale sightings. Approximately 32% of useable Chukchi Sea cetacean sightings were bowhead whales in 2006 compared to 9% in 2007, while gray whale sightings comprised only 29% of useable observations in 2006 compared to 50% in 2007 (Table 3.4)

TABLE 3.4. All useable cetacean sightings (number of individuals) recorded by MMOs from source and support vessels during 2006 and 2007 Chukchi Sea operations.

Species	Source Vessels		Support Vessels		Annual Totals	
	2006	2007	2006	2007	2006	2007
Cetaceans						
Unidentified Whale	1 (2)	1 (1)	11 (13)	2 (2)	***12 (15)***	***3 (3)***
Mysticetes						
Bowhead Whale	3 (3)	3 (4)	22 (41)	3 (3)	***25 (44)***	***6 (7)***
Minke Whale	2 (2)	0	1 (1)	3 (3)	***3 (3)***	***3 (3)***
Gray Whale	0	2 (2)	23 (43)	30 (64)	***23 (43)***	***32 (66)***
Humpback Whale	0	0	0	2 (3)	***0***	***2 (3)***
Unidentified Mysticete Whale	2 (2)	0	1 (1)	6 (10)	***3 (3)***	***6 (10)***
Odontocetes						
Killer Whale	0	1 (1)	1 (2)	0	***1 (2)***	***1 (1)***
Harbor Porpoise	3 (5)	3 (4)	6 (11)	7 (12)	***9 (16)***	***10 (16)***
Unidentified Dolphin	0	0	3 (4)	0	***3 (4)***	***0***
Unidentified Odontocete Whale	0	0	0	1 (1)	***0***	***1 (1)***
Total Cetaceans	***11 (14)***	***10 (12)***	***68 (116)***	***54 (98)***	***79 (130)***	***64 (110)***

Detection Rates by Season.—In 2006, summer cetacean detection rates from support vessels were similar to those from source vessels however, but in fall cetacean detection rates from support vessels were nearly ten times those of source vessels (Fig. 3.16). Trends in 2007 showed peak cetacean detection rates occurring in summer from both support and source vessels. In addition, cetacean detection rates from source vessels in summer were much higher than from support vessels. No useable cetacean sightings were made from source vessels during fall 2007 (Fig. 3.16). Low sample sizes in some categories made meaningful comparison of cetacean detection rates between years and seasons difficult

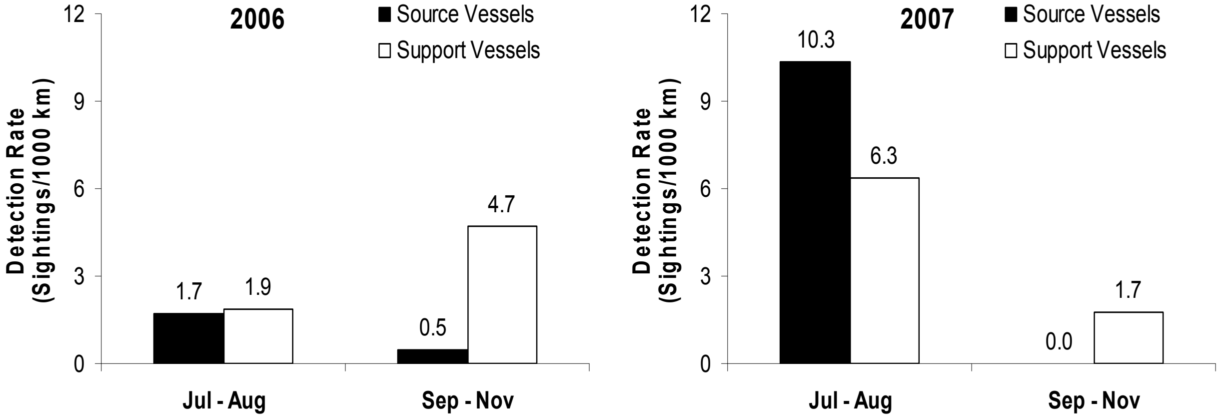

FIGURE 3.16. Detection rates from useable cetacean sightings by season recorded during 2006 and 2007 Chukchi Sea vessel operations.

Detection Rates by Seismic State.—The cetacean detection rate was greater during non–seismic periods than seismic periods from both source and support vessels in 2006 and 2007 (Fig. 3.17; Appendix Table A.6). Cetacean detection rates were similar from source and support vessels during seismic periods in 2006. This was also the case during non–seismic periods in 2006. In 2007 the differences in detection rates between source and support vessels during seismic and non–seismic periods were greater. The cetacean detection rate from source vessels was over twice that reported from support vessels during non–seismic periods in 2007, and approximately twice as high as the non–seismic detection rate from both source and support vessels in 2006. No cetacean sightings were reported from source vessels during seismic periods in 2007.

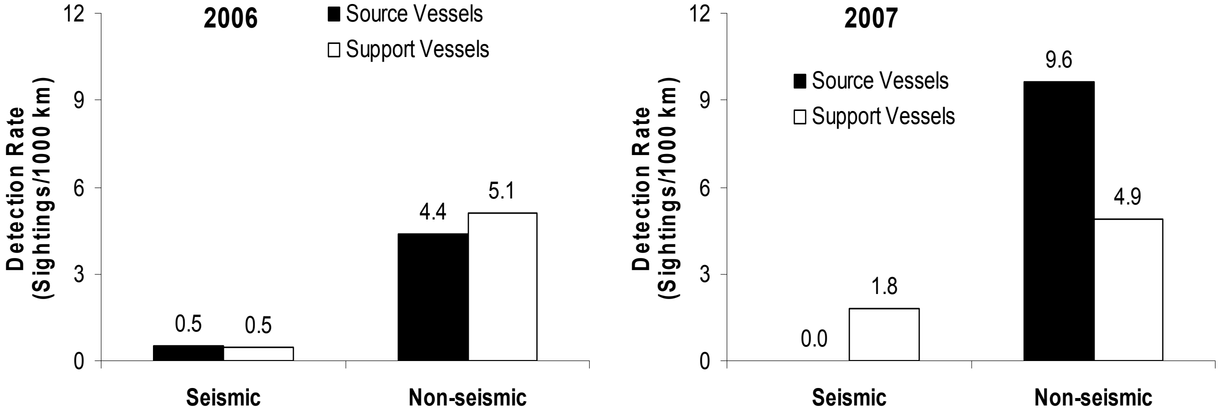

FIGURE 3.17. Detection rates from useable cetacean sightings by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations.

In addition to comparing cetacean detection rates between seismic and non-seismic periods based on useable data from source and support vessels, seismic and non-seismic detection rates in 2007 were also compared among various vessel types based on useable data vs. all data (i.e., useable and non-useable data combined; Table 3.5). This was done to determine what effect the use of non-useable data may have on calculations of cetacean detection rates. For this analysis cetacean detection rates were calculated from the source vessel (*Gilavar*), from all support vessels combined, and from support vessels during the periods when they operated as chase vessels for the *Gilavar*. Chase vessel activities were concentrated within a few km of the *Gilavar* allowing for a comparison the two vessel types operating in the same area. Non-chase support vessels operated over a much wider area and were often not in the same area of the Chukchi Sea as the *Gilavar*.

Cetacean detection rates based on all data combined were lower than detection rates based on useable data during non-seismic periods. This would be the expected result since overall sighting conditions based on useable data were better than conditions that included non-useable data. This was not the case during seismic periods where densities based on all data were slightly greater than those based on useable data. However, the useable seismic detection rates from source and chase vessels were based on <500 km of effort and should be viewed with caution, and the detection rate from support vessels (1.8 detections/1000km) was based on only 558 km of effort. In all comparisons cetacean detection rates were higher during non-seismic than seismic periods suggesting possible cetacean avoidance of the seismic survey area. The trend in this analysis was similar to that of the previous analysis based solely on useable data (Fig. 3.17).

TABLE 3.5. Cetacean detection rates (sightings/1000km of trackline) from the source vessel (*Gilavar*), all support vessels, and all chase vessels during seismic and non-seismic periods in the Chukchi Sea 2007 based on useable data and all data (useable and non-useable) combined. Bold figures indicate values base on <500 km of effort.

	Cetacean Detection Rate			
	Useable Data		All Data	
	Seismic	Non-seismic	Seismic	Non-seismic
Source Vessel	**0.0**	9.6	2.0	4.3
All Support Vessels	1.8	4.9	2.1	3.6
Chase Vessels	**2.0**	4.2	2.2	3.4

Distribution

Initial sightings relative to vessels.—The bearing and distance to cetaceans when first detected were determined for all useable sightings during seismic and non–seismic periods from source and support vessels (Fig. 3.18–3.21). Bearing and distance were calculated from the airgun array for sightings from the source vessels and from the observer station for sightings from the support vessels. There were no useable cetacean sightings recorded from the source vessel during seismic periods in 2007.

There were few cetacean sightings (*n* = 11) to compare cetacean distribution between seismic and non–seismic periods from source vessels in 2006. Cetaceans appeared to be more dispersed during seismic than non–seismic periods (Fig. 3.18). Most cetaceans were sighted ahead and to the sides of the vessel tracklines. Distribution predominantly forward of the vessel was expected because observers scan ahead of the vessel in order to initiate mitigation procedures before animals enter the safety zone.

No cetacean sightings were recorded during seismic periods from source vessels in 2007. The distribution of cetacean sightings from support vessels during non–seismic periods in 2007 was primarily forward of the vessel with one aft sighting (Fig. 3.19).

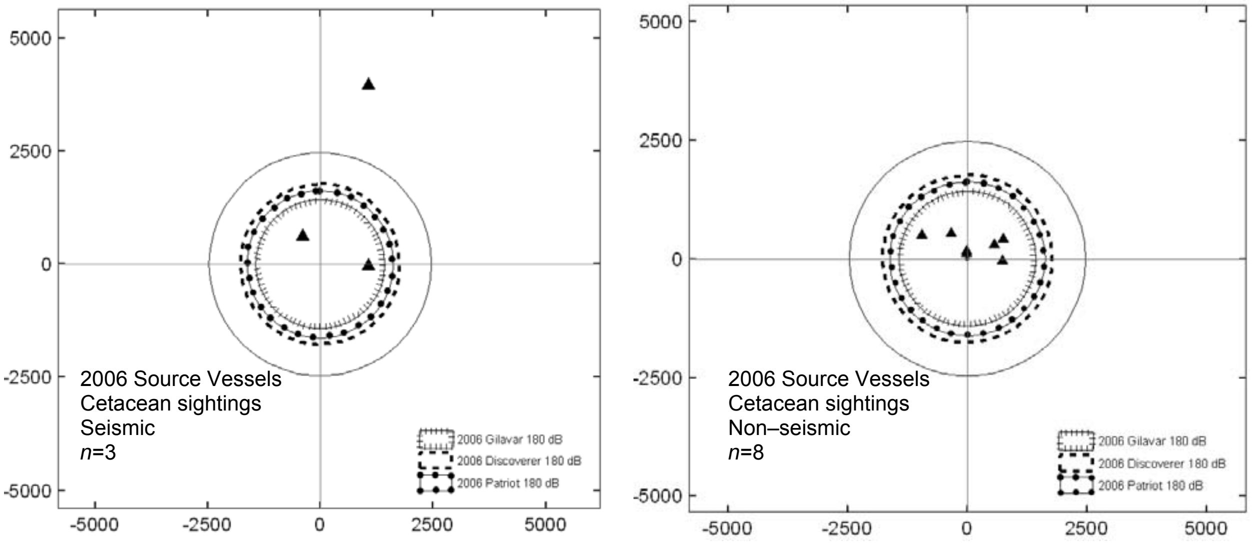

FIGURE 3.18. Relative locations of useable cetacean sightings from the source vessels during 2006 seismic operations in the Chukchi Sea. The ≥180 dB sound level radii of the full airgun arrays are displayed for each of the source vessels (*Methods* section). The locations indicate distance (m) from the airgun array, aft of the observer. The distance between x and y axis tick marks (2500 m) = 1.6 mi.

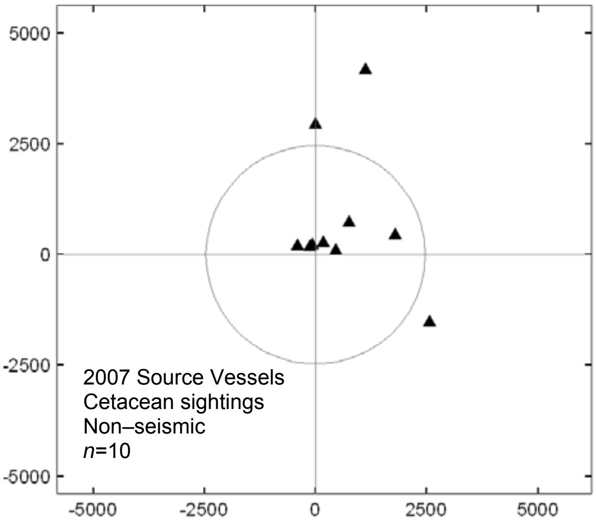

FIGURE 3.19. Relative location of useable non–seismic cetacean sightings from the source vessel in the Chukchi Sea, 2007. The ≥180 dB sound level radius is displayed (2.47 km or 1.5 mi). The sighting locations indicate distance (m) from the airgun array located 300 m (328 yd) aft of the observer station. The distance between x and y axis tick marks (2500 m) = 1.6 mi.

Few cetacean sightings were recorded from support vessels during seismic periods in 2006 (Fig. 3.20). Most cetacean sightings were close to the vessel and one sighting was forward of the vessel. More sighting were recorded from support vessels during non–seismic than seismic periods in 2006. Most sightings were forward and to the sides of the vessel with one aft sighting.

Only one sighting was recorded from support vessels during seismic periods in 2007 (Fig. 3.21). As in 2006, more cetaceans were sighted from support vessels during non–seismic than seismic periods. The distribution of cetacean sightings from support vessels in 2007 was similar to the distribution in 2006 although sightings appeared to be slightly more dispersed in 2007.

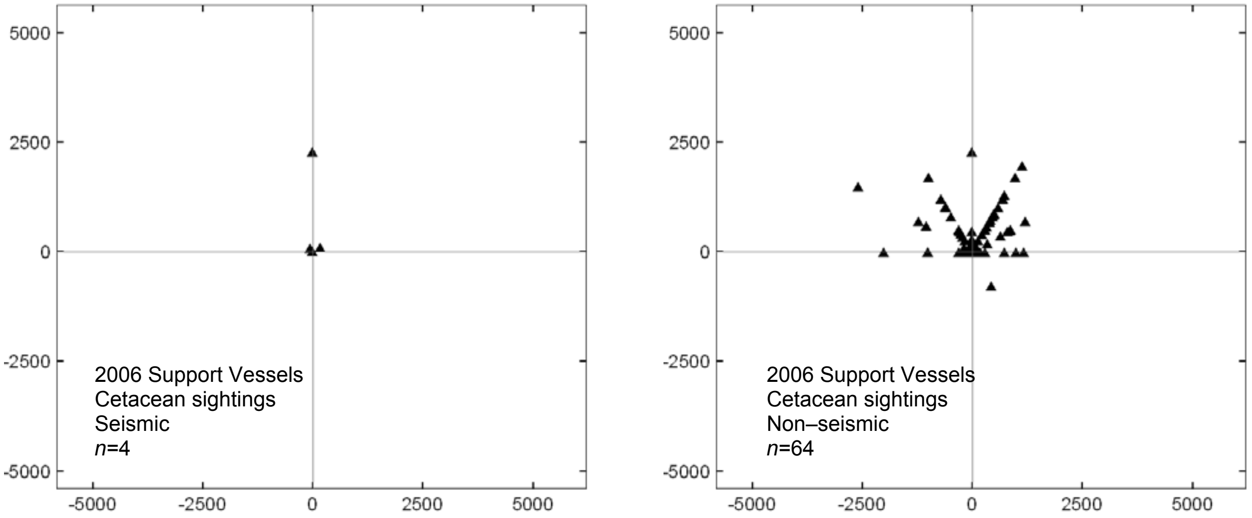

FIGURE 3.20. Relative location of useable cetacean sightings from the support vessels in the Chukchi Sea, 2006. The locations indicate distance (m) from the observer station. The distance between x and y axis tick marks (2500 m) = 1.6 mi.

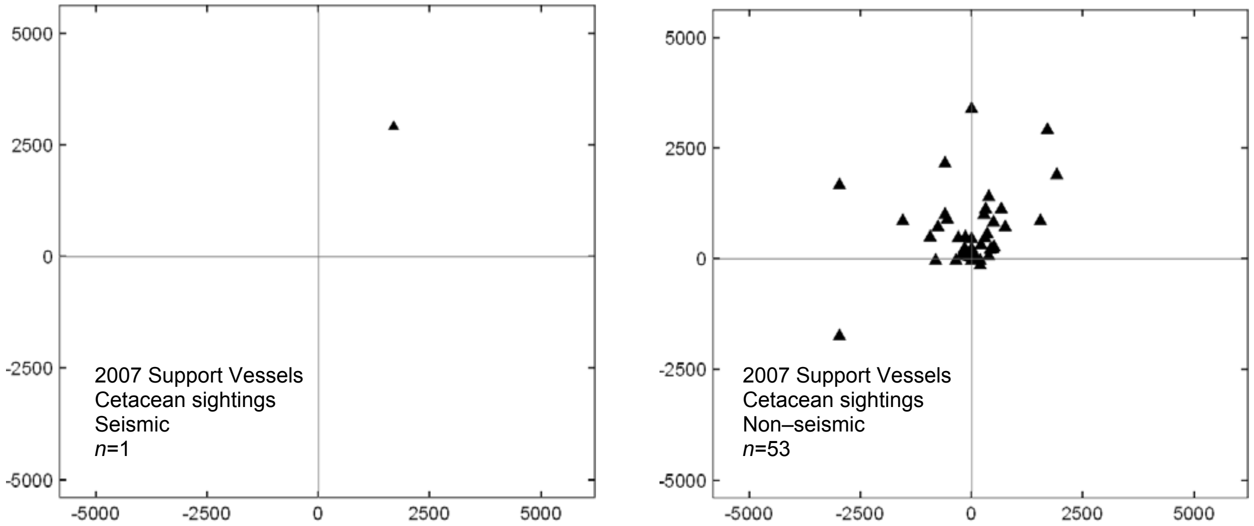

FIGURE 3.21. Relative location of useable cetacean sightings from the support vessels in the Chukchi Sea, 2007. The locations indicate distance (m) from the observer. The distance between x and y axis tick marks (2500 m) = 1.6 mi.

Closest Point of Approach.—In general, cetaceans approached source vessels more closely during non–seismic than seismic periods in 2006 though this trend was based on a small sample size (*n*=11; Table 3.6). The cetacean CPA was the same for support vessels during seismic and non–seismic periods in 2006. In 2007, no cetacean sightings were made from source vessels during seismic periods. For support vessels, sightings in 2007 were closer on average during non–seismic periods (860 m; 940 yd) than during seismic periods (3423 m; 3743 yd). Cetacean CPAs for source vessels were greater in 2007 compared to 2006 during both seismic and non–seismic periods, especially during seismic conditions. Average cetacean CPAs from source vessels during seismic and non–seismic periods were greater in 2007 than in 2006, though this difference was small (Table 3.6).

TABLE 3.6. Comparison of cetacean CPA distances by seismic period from useable sightings aboard source and support vessels during 2006 and 2007 Chukchi Sea vessel operations.

Effort Category	**Mean CPA[a] (m)**	**s.d.**	**Range (m)**	***n***
2006				
Source Vessels Seismic	2071	1914	824-4275	*3*
Source Vessels Non-seismic	908	333	450-1400	*8*
Source Vessels Mean	***1225***	***1051***	***450-4275***	***11***
Support Vessels Seismic	652	1093	20-2287	*4*
Support Vessels Non-seismic	652	622	5-2979	*64*
Support Vessels Mean	***652***	***646***	***5-2979***	***68***
2007				
Source Vessels Seismic	*NA*	*NA*	*NA*	*0*
Source Vessels Non-seismic	1399	1197	309-3004	*10*
Source Vessels Mean	***1399***	***1197***	***309-3004***	***10***
Support Vessels Seismic	3423	*NA*	*NA*	*1*
Support Vessels Non-seismic	860	922	50-3423	*53*
Support Vessels Mean	***908***	***978***	***50-3423***	***54***

[a] CPA = *Closest Point of Approach*. For source vessels this value is the marine mammal's closest point of approach to the airgun array, for support vessels this value is the marine mammal's closest point of approach to the MMO/vessel.

Distance from Ice Detection Rates.—Useable cetacean sightings within 20 km (12.4 mi) of ice for source and support vessels in 2006 (*n* = 3 and 14, respectively) and 2007 (*n* = 2 and 4, respectively) were too few for meaningful analyses and interpretation of trends. Detection rates in 2006 were higher in areas with greater than 10% ice cover for both source and support vessels (Fig. 3.22). In 2007 no sightings were made in areas with ice cover from source vessels and sightings were only made in areas with greater than 10% ice cover from support vessels. Peak cetacean detection rates from the source vessel in 2007 were recorded at a distance of 10–15 km (6.2–9.3 mi) from ice, a distance at which no sightings were made the previous year. This may have resulted from the reduced ice conditions in 2007 compared to 2006. No strong trends with respect to distance from ice appear in either 2006 or 2007 (Fig. 3.22).

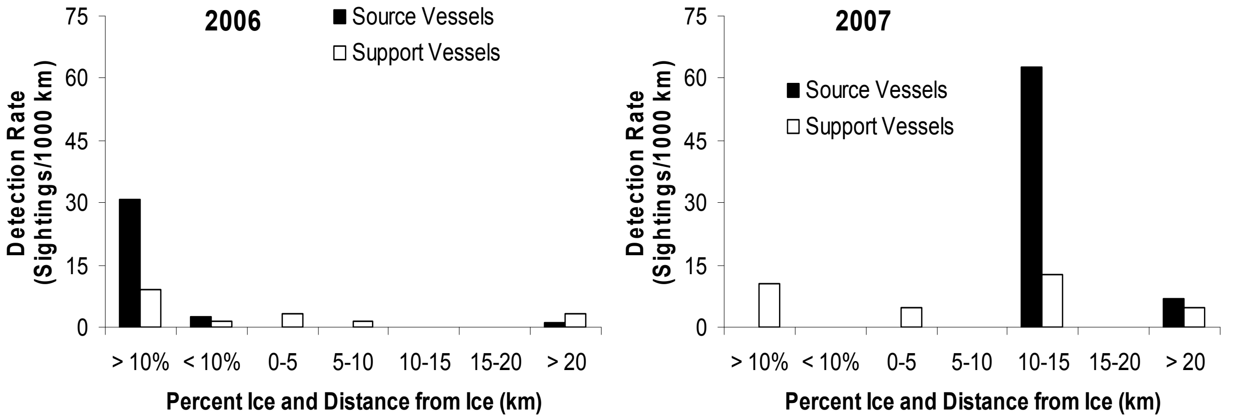

FIGURE 3.22. Detection rates from useable cetacean sightings by percent ice and distance from ice recorded during 2006 and 2007 Chukchi Sea vessel operations.

Distance from Shore Detection Rates.—Cetacean detection rates from support vessels were highest in nearshore areas less than 25 km (15.5 mi) from shore in both 2006 and 2007 (Fig. 3.23). Source vessels generally did not operate near shore and no cetacean sightings were made from sources vessels within 25 km from shore. In 2006, detection rates in areas greater than 25 km (15.5 mi) from shore were higher from support vessels than from source vessels. In 2007, detection rates between source and support vessels in areas greater than 25 km (15.5 mi) offshore were equivalent (Fig. 3.23).

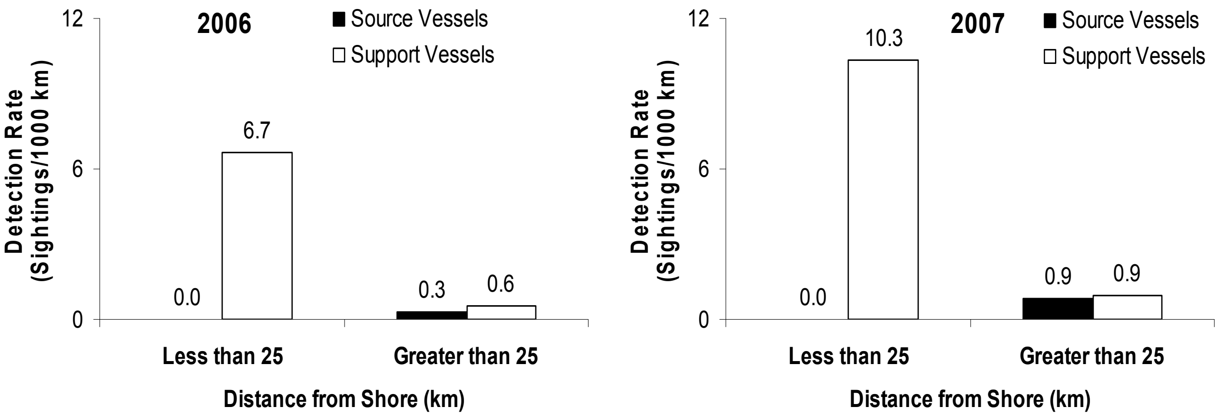

FIGURE 3.23. Detection rates from useable cetacean sightings by distance from shore for 2006 and 2007 Chukchi Sea vessel operations.

Behavior

Movement.—Of the three cetaceans observed during seismic operations from source vessels in 2006, relative movement of two animals could not be determined and movement of the third was neutral (Fig. 3.24). Movement of all four cetaceans observed from support vessels during seismic conditions was neutral to the vessel. Neutral movement consisted of milling or moving perpendicular or parallel to the vessel at a sedate or moderate pace. The predominant cetacean movement recorded during non–seismic periods from both source and support vessels in 2006 was also neutral to the vessel. Movements suggesting possible reaction to the vessel such as swim away and swim toward were also recorded from support and source vessels during non–seismic periods in 2006.

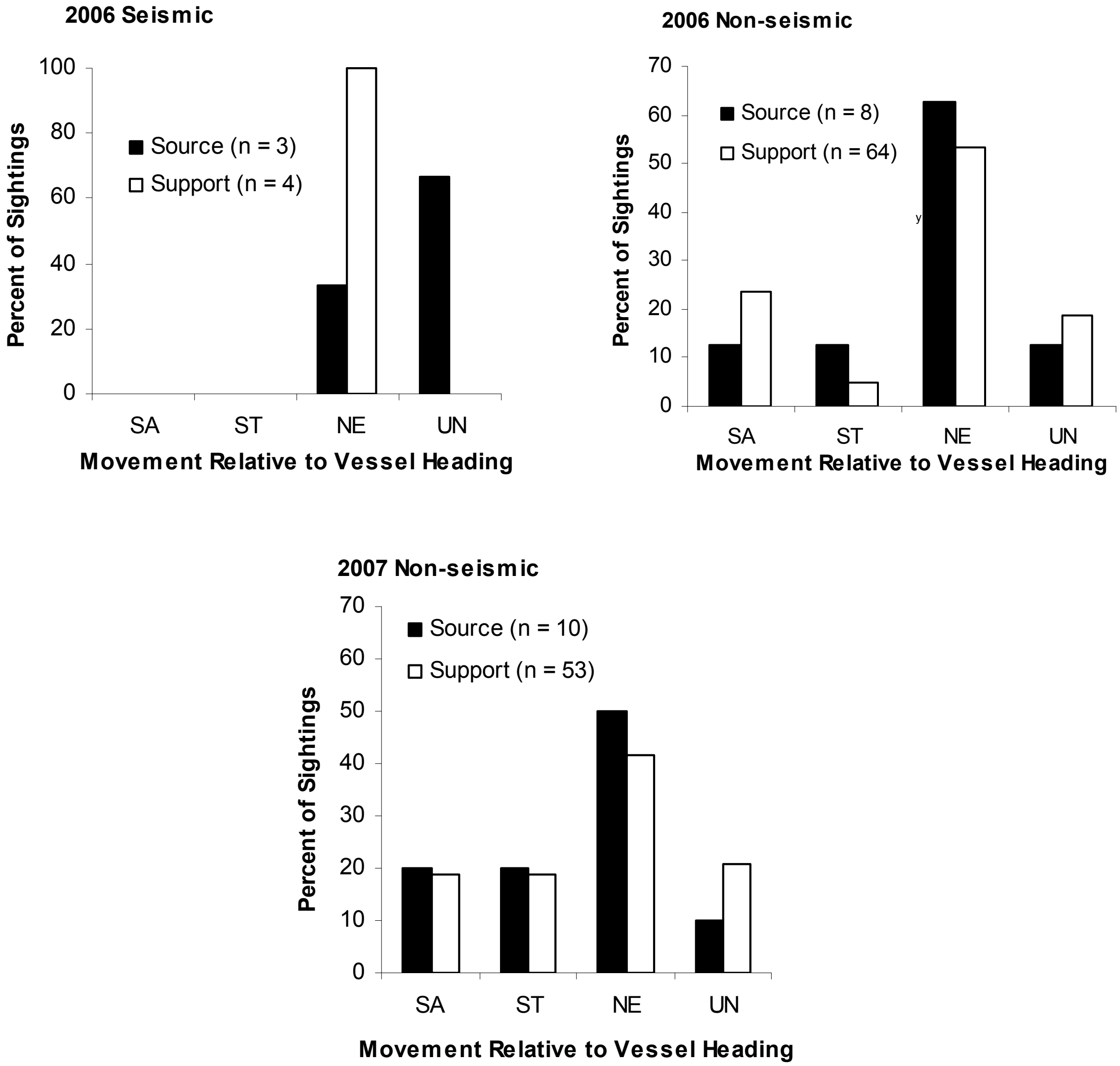

FIGURE 3.24. Percent of movement relative to vessels for useable cetacean sightings by seismic state for 2007 and 2006 Chukchi Sea survey operations. SA = Swim Away, ST = Swim Toward, NE = Neutral, UN = Unknown.

There were no useable cetacean sightings from the source vessel during seismic periods in 2007. Only one cetacean sighting of an animal moving away from the vessel was recorded from support vessels during seismic periods in 2007.

As was the case in 2006, the majority of cetacean movement recorded from source and support vessels in 2007 during non–seismic periods was neutral to the vessel (Fig. 3.24). Movements indicating avoidance were also recorded from source and support vessels during non–seismic periods in 2007 (Fig. 3.24). This pattern was similar to that recorded in 2006.

Initial Behavior.— The most frequently observed initial cetacean behaviors in both 2006 and 2007 were surface active, swimming, and diving regardless of seismic state. Feeding and resting were occasionally observed from support vessels during non–seismic periods, but this may be an artifact of the small sample sizes in both years (*n*=7 and 1 in 2006 and 2007, respectively; Fig. 3.25).

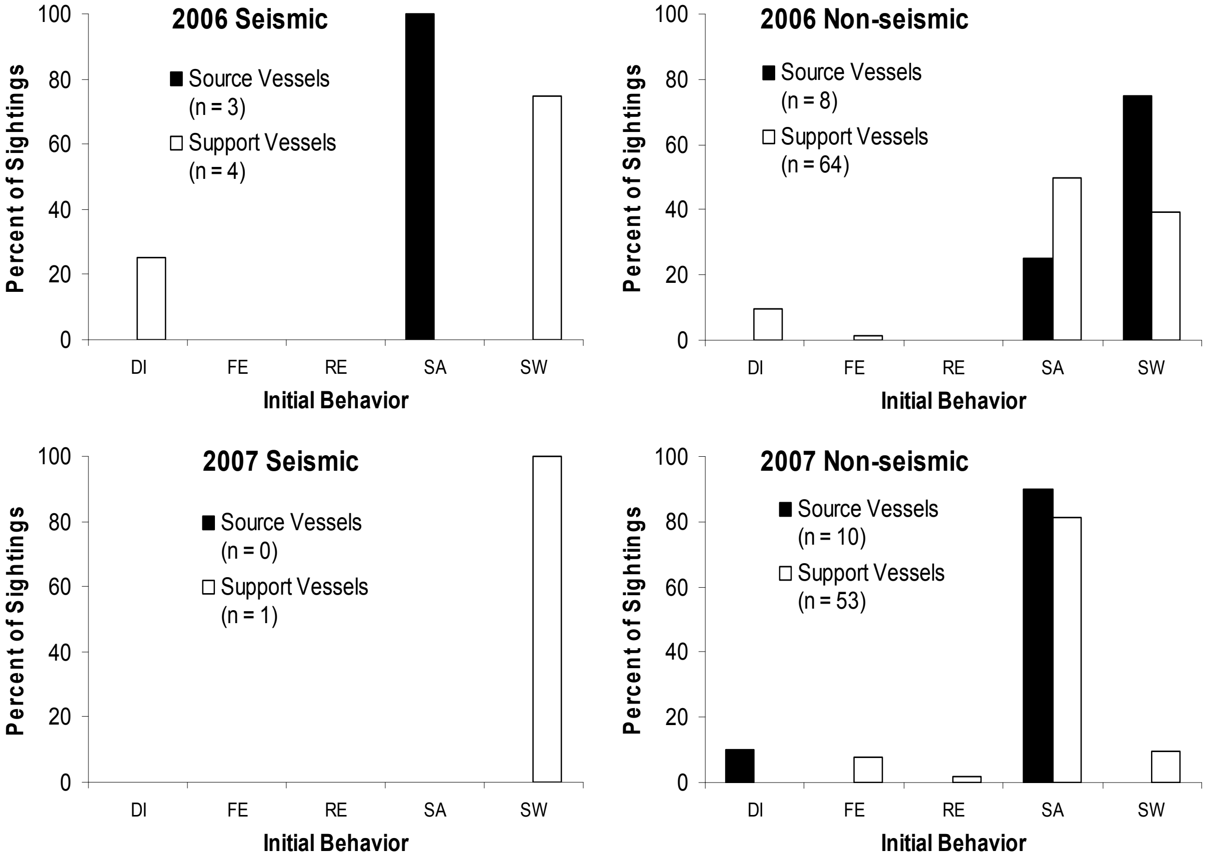

FIGURE 3.25. Percent of useable cetacean sightings performing initial behavior by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations. DI = Dive, FE = Feed, RE = Rest, SA = Surface Active, SW = Swim.

Reaction Behavior.—The majority of cetaceans exhibited no reaction to source or support vessels in either year, regardless of seismic state. A change in direction was the most commonly observed reaction, accounting for slightly over 20% of observed reactions during non–seismic periods in 2006. An increase in speed and splashing were the only other observed reaction behaviors and were only observed during non–seismic periods in 2006, accounting for less than 10% of observed reactions (Fig. 3.26). Sample sizes, especially for seismic periods, were low (*n*=8) and caution should use when interpreting these results.

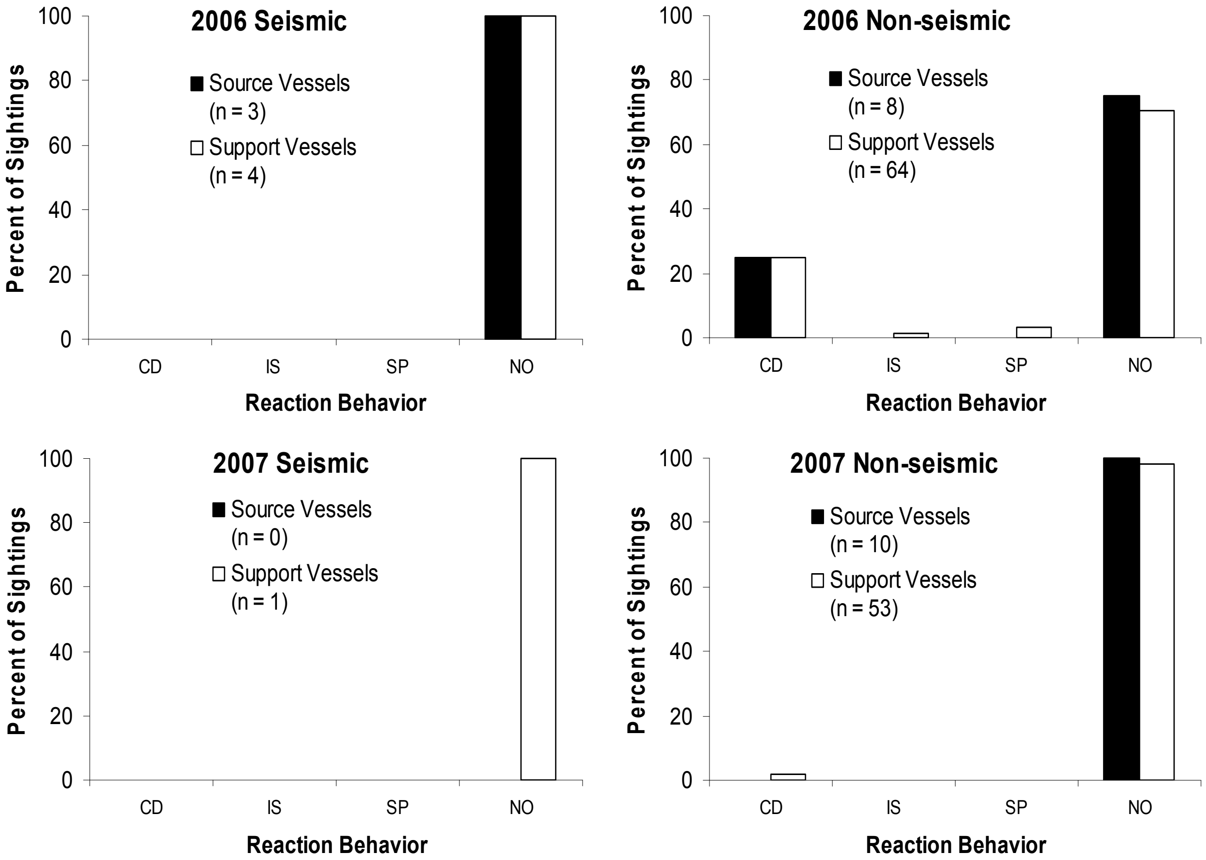

FIGURE 3.26. Percent of useable cetacean sightings performing reaction behavior by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations. CD = Change Direction, IS = Increase Speed, SP = Splash, NO = No Reaction.

Cetacean Detection Rates Relative to Received Sound Levels

Based on useable data collected aboard support vessels, one cetacean (3.6/1000 km) was detected within the area where received sound levels were estimated to be ≥150 dB rms in the Chukchi Sea during 2007, and no cetaceans were detected in areas ensonified to ≥160 dB rms (Table 3.7). However, there was no useable effort from support vessels within the area where received sound levels were estimated to exceed 170 dB (rms) and less than 500 km of useable effort in each of the areas ensonified to levels between 120 and 170 dB (rms). Because the amount of useable effort was different between years and was marginal in 2007, comparison of cetacean exposure level data in 2006 and 2007 was problematic. If cetaceans were avoiding the sound source, detection rates should have decreased as received sound levels increased.

TABLE 3.7. Number of detections, amount of useable effort (km), and detection rates (detections/1000 km) for cetaceans exposed to various sound levels in the Chukchi Sea during 2006 and 2007 based on data collected on support vessels only.

	2006			2007		
Received Sound Exposure Level (dB re1 µPa rms)	Number of Sightings	Useable Effort (km)	Detection Rate (sightings / 1000 km)	Number of Sightings	Useable Effort (km)	Detection Rate (sightings / 1000 km)
< 120	51	7758.5	6.6	11	2158.7	5.1
120 - 129	1	1397.9	0.7	0	419.6	0.0
130 - 139	0	2260.8	0.0	0	338.1	0.0
140 - 149	0	969.3	0.0	0	205.8	0.0
150 - 159	0	1686.0	0.0	1	279.3	3.6
160 - 169	4	4943.5	0.8	0	83.4	0.0

Probability of Cetacean Detection with Distance from Vessel

The effect of number of observers and Beaufort wind force on initial sighting distance was considered separately for vessels with observation platforms higher and lower than 12 meters (13 yards). For vessels with observation platforms higher than 12 m, the effective strip half–width (ESW) ranged from 1820 m (1990 yds) to 2831 m (3096 yds; Fig. 3.27). The ESW increased by 36% as the number of observers was increased from one to two during periods when Beaufort wind force was low (0–2), however, during periods when Beaufort wind force was higher (3–5), increasing the number of observers from one to two did not increase the ESW. This result suggested that there was some benefit to increasing the number of observers when sighting conditions were favorable, but that little was gained by using additional observers when sighting conditions were poor.

For vessels with observation platforms lower than 12 m, the ESW ranged from 1185 m (1296 yds) to 1583 m (1731 yds; Fig. 3.27). In contrast to the trend identified for the taller vessels, the ESW for vessels with lower observation platforms increased by 22% as the number of observers increased from one to two when Beaufort wind force was high (3–5). However, the number of observers did not have a considerable effect on ESW when Beaufort wind force was lower (0–2). Among vessels with low observation platforms, the sample size for periods with two observers was much smaller than for one observer, therefore unequal sample sizes may have influenced the results.

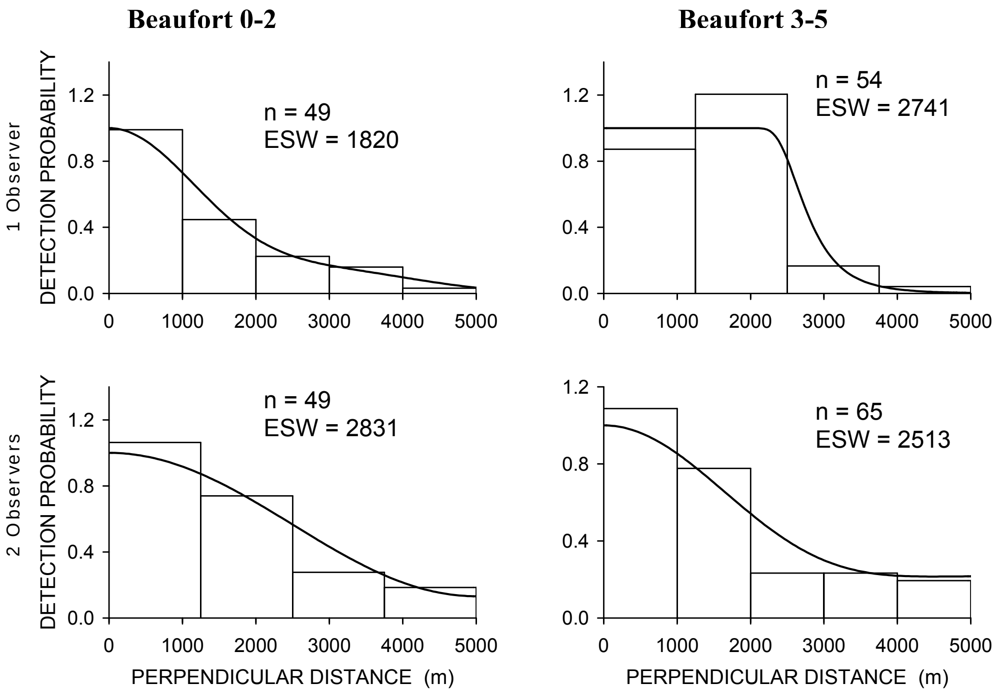

FIGURE 3.27. Effect of number of observers and Beaufort wind force on the detection probability of mysticete whales. Data considered in this analysis were collected on vessels with observation platforms 12.4 – 27.0 m in height and the analysis includes data collected outside of the Chukchi and Beaufort sea study areas during 2006–07.

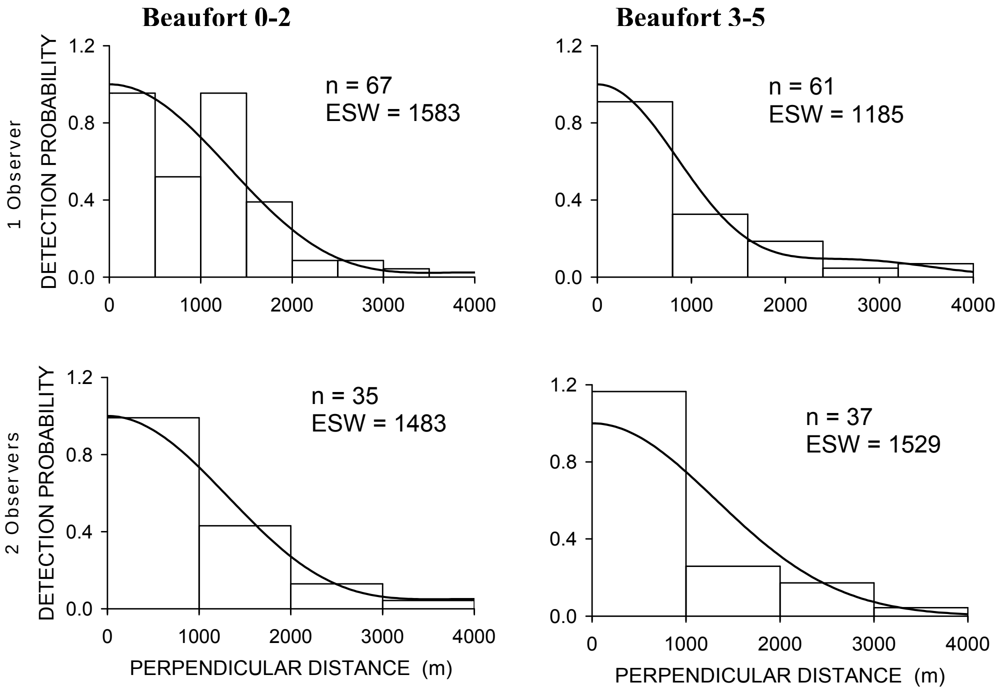

FIGURE 3.28. Effect of number of observers and Beaufort wind force on the detection probability of mysticete whales. Data considered in this analysis was collected on vessels with observation platforms 5.0 – 10.2 m in height and includes data collected outside of the Chukchi and Beaufort Sea study areas during 2006–07.

Estimated Number of Cetaceans Potentially Ensonified

Estimates from direct observations.—The number of cetaceans directly observed within the areas where received sound levels were ≥160 and 180 dB re 1 µPa (rms) provided a minimum estimate of the number of individuals potentially exposed to sound at these levels. For this analysis, data were not filtered using the useability criteria outlined in the *Methods* section. During 2007, 15 and 5 cetaceans were observed within the area where received levels were estimated to be ≥160 and 180 dB re 1 µPa (rms), respectively (Table 3.8). The numbers of cetaceans exposed to received levels ≥160 and 180 dB were higher in 2006 (34 and 8, respectively). It is possible that some marine mammals present within these areas were not detected by observers, and therefore these numbers likely underestimate the number of individual cetaceans ensonified to sound ≥160 and 180 dB re 1 µPa (rms).

TABLE 3.8. Total number of sightings (and individual) cetaceans observed from all vessels combined within the ≥160 and 180 dB re 1 µPa (rms) radii of seismic airguns in 2006 and 2007.

Received Exposure Level (dB re1 µPa rms)	Individuals	
	2006	**2007**
≥160	32(34)	8(15)
≥180	7(8)	2(5)

Estimates Extrapolated from Density.—Table 3.9 presents cetacean density estimates that account for animals not detected by observers in 2007 due to sightability bias. (For more detailed explanation of the methods, please refer to Appendix F.) Based on useable data collected during non–seismic periods, cetacean density in the Chukchi Sea was estimated at approximately 7.9 and 3.8 individuals per 1000 km^2 (386 mi^2) during the summer and fall, respectively. In contrast, the fall density estimate calculated using seismic period data was only 0.8 individuals per 1000 km^2 (386 mi^2), suggesting that cetaceans may have avoided areas of seismic activity. There was an insufficient amount of data available to calculate a summer seismic period density estimate.

The estimated numbers of cetaceans exposed to various sound levels during 2006 and 2007 seismic operations are presented in Tables 3.10 and 3.11. These values are from Shell's 2007 operations 90–day report (Funk et al. 2008) and the 2006 Joint Monitoring Program (JMP) report (Funk et al. 2007). The amount of useable effort from vessels directly involved with seismic operations in the Chukchi Sea in 2007 was not sufficient to produce reliable density estimates. As an alternative, all daylight effort and sightings from these vessels were used to calculate the density estimates used in estimating exposures (for details see Funk et al. 2008). Estimates for 2007 use a summer period that extended to 10 Sep to include all of the seismic activity that occurred in the Chukchi Sea before the *Gilavar* moved into the Beaufort Sea (Funk et al. 2008). Non–seismic estimates represent the number of animals that would have been exposed had they not shown localized avoidance behavior in response to the airguns or the vessels themselves. Some of the individuals estimated to be within a given safety or disturbance radius would likely have moved away before being exposed to sounds that strong.

In 2006, cetacean seasons were defined based on the migration patterns of bowhead whales. The early season for cetaceans was considered to be the period prior to 25 Sep, the mid–season was 25 Sep–25 Oct, and the late season was from 26 Oct onward. Because environmental conditions often change between years, it is possible that species–specific seasons would change annually, complicating multi–year analyses. In 2006 the data were also partitioned by nearshore and offshore, whereas in 2007 there were insufficient data to make inshore vs. offshore comparisons.

TABLE 3.9. Cetacean density estimates based on useable data collected in the Chukchi Sea during 2007. Dashes (–) indicate categories in which insufficient (<500 km or 310 mi) useable effort were collected to calculate a density estimate.

		No. individuals / 1000km^2		
		Summer	Fall	
Vessel Type	**Species**	**Non-Seismic**	**Seismic**	**Non-Seismic**
Source Vessels				
	Bowhead Whale	0.9	-	-
	Gray Whale	0.5	-	-
	Killer Whale	0.4	-	-
	Harbor Porpoise	6.5	-	-
	Unidentified Whale	0.2	-	-
	Source Vessel Total	**8.5**	**-**	**-**
Support Vessels				
	Bowhead Whale	0.1	-	0.1
	Gray Whale	3.9	-	1.1
	Humpback Whale	0.2	-	0.0
	Minke Whale	0.7	-	0.0
	Unidentified Mysticete Whale	0.4	-	0.6
	Harbor Porpoise	2.2	-	2.1
	Unidentified Toothed Whale	0.1	-	0.0
	Unidentified Whale	0.1	-	0.0
	Support Vessel Total	**7.7**	**-**	**3.9**
All Vessels				
	Bowhead Whale	0.2	0.0	0.1
	Gray Whale	3.5	0.8	1.1
	Humpback Whale	0.2	0.0	0.0
	Minke Whale	0.6	0.0	0.0
	Unidentified Mysticete Whale	0.4	0.0	0.6
	Killer Whale	0.04	0.0	0.0
	Harbor Porpoise	2.8	0.0	2.1
	Unidentified Toothed Whale	0.1	0.0	0.0
	Unidentified Whale	0.1	0.0	0.0
	All Vessel Total	**7.9**	**0.8**	**3.8**

- indicates less than 500 km of useable effort

In 2007, we estimated that nine and five individual cetaceans may have been exposed to received levels ≥160 and 180 dB (rms), respectively. In 2006, it was estimated that up to 4,183 and 1,043 individual cetaceans may have been exposed at these levels. Because these estimates are based on data collected during non–seismic periods, they are considered conservative in that they do not account for behavioral reactions of animals moving away from the seismic activities during seismic periods. The large difference in these estimates between years is partially due to the greater amount of seismic activity that occurred in 2006 when three different vessels performed seismic surveys compared to 2007 when a single vessel performed seismic surveys.

TABLE 3.10. Estimated numbers of individual cetaceans ensonified to sound levels ≥160, 170, 180, and 190 dB (rms), and average number of exposures per individual in both the nearshore and offshore regions, using ***(A)*** Non–seismic densities, and ***(B)*** Seismic densities, from useable[a] data in 2006. Estimates in ***(A)***, based on non–seismic densities, undoubtedly overestimate actual numbers of cetaceans exposed to high–level sounds, given that cetaceans commonly avoid approaching seismic vessels.

		Nearshore		**Offshore**		***Total***	
	Exposure level in dB re 1μPa (rms)	**Individuals**	**Exposures / Individual**	**Individuals**	**Exposures / Individual**	**Individuals**	**Exposures / Individual**
A. Non-seismic density							
Early season	**≥160**	0	0.0	613	14.4	613	14.4
	≥170	0	0.0	424	11.4	424	11.4
	≥180	0	0.0	258	6.6	258	6.6
	≥190	0	0.0	184	3.1	184	3.1
Mid-season	**≥160**	38	1.0	2661	2.7	2699	2.7
	≥170	16	1.0	1375	2.2	1391	2.2
	≥180	6	1.0	582	1.7	587	1.7
	≥190	2	1.0	204	1.5	206	1.5
Late season	**≥160**	0	0.0	871	1.3	871	1.3
	≥170	0	0.0	497	1.2	497	1.2
	≥180	0	0.0	198	1.1	198	1.1
	≥190	0	0.0	61	1.1	61	1.1
All seasons	**≥160**	38	1.0	4145	4.1	***4183***	***4.1***
	≥170	16	1.0	2296	3.7	***2312***	***3.7***
	≥180	6	1.0	1038	2.8	***1043***	***2.8***
	≥190	2	1.0	449	2.1	***451***	***2.1***
B. Seismic density [b]							
Early season	**≥160**	0	0.0	73	14.4	73	14.4
	≥170	0	0.0	51	11.4	51	11.4
	≥180	0	0.0	31	6.6	31	6.6
	≥190	0	0.0	22	3.1	22	3.1
Mid-season	**≥160**	2	1.1	131	2.7	132	2.7
	≥170	1	1.0	67	2.2	68	2.2
	≥180	0	1.0	29	1.7	29	1.7
	≥190	0	1.0	10	1.5	10	1.5
Late season	**≥160**	0	0.0	104	1.3	104	1.3
	≥170	0	0.0	59	1.2	59	1.2
	≥180	0	0.0	24	1.1	24	1.1
	≥190	0	0.0	7	1.1	7	1.1
All seasons	**≥160**	2	1.1	308	5.0	***310***	***5.0***
	≥170	1	1.0	177	4.5	***178***	***4.5***
	≥180	0	1.0	84	3.3	***84***	***3.3***
	≥190	0	1.0	39	2.3	***39***	***2.3***

[a] See *Useability Criteria* in *Methods* section in this Chapter.

[b] The offshore seismic density was used in both the nearshore and offshore calculations.

TABLE 3.11. Estimated numbers of individual cetaceans exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual within the Chukchi Sea during both the summer and fall survey periods in 2007. Requested number of cetacean exposures for the Chukchi Sea in 2007 was 2987. Estimates are based on "corrected" densities of cetaceans calculated from daylight MMO watch effort using seismic and non–seismic densities.

	Non-seismic Densities		Seismic Densities	
Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures per Individual**	**Individuals**	**Exposures per Individual**
Summer				
≥160	9	18.5	7	18.5
≥170	6	13.4	5	13.4
≥180	4	8.9	3	8.9
≥190	2	3.9	2	3.9
Fall				
≥160	1	13.7	0	13.7
≥170	1	9.7	0	9.7
≥180	0	7.0	0	7.0
≥190	0	3.4	0	3.4
Total*				
≥160	9	26.0	7	26.0
≥170	6	17.7	5	17.7
≥180	5	11.5	3	11.5
≥190	2	3.6	2	3.6

* Totals may not add up to sum of summer and fall values due to rounding

Seals

Sightings

Total Sightings.—In total, 1724 useable seal sightings comprised of an estimated 1933 individuals were recorded by source and support vessel MMOs in the Chukchi Sea during 2006 (Table 3.12). The most common seal sightings in 2006 were of small seals consisting of ringed, spotted, and unidentified seals combined, followed by bearded seals. The numbers of marine mammal sightings regardless of usability criteria for source and support vessels during 2006 and 2007 are listed in Appendix Table A.5.

The 2007 Chukchi Sea total of 232 useable seal (and single sea lion) sightings was over seven times fewer than the number of useable seal sightings recorded in 2006, though the species composition was comparable between the two years (Table 3.12). The lower number of seal sightings in 2007 was due to lower detection rates and the reduced amount of useable effort in 2007 compared to 2006. The single sighting of a Steller sea lion in the Chukchi Sea from a support vessel MMO was unusual as this was outside the typical range of this species. The sea lion sighting was included in all following "seal" analyses.

The 2006–2007 seal total included 35 sightings of 40 unidentified large brown pinnipeds, and it is possible that some of these animals were Pacific walruses. The ratio of identified bearded seal to Pacific walrus *sightings* in the Chukchi Sea during 2006–2007 was 253 to 461 (Table 3.3). A proportional reallocation of the 35 unidentified large brown pinniped sightings would increase bearded seal and Pacific walrus sightings by 12 and 23, respectively. However, the ratio of identified *individual* bearded seals to Pacific walruses in the Chukchi Sea for 2006–2007 was 311 to 4049 (Table 3.3). Proportional reallocation of the 40 individual unidentified pinnipeds would result in an additional three bearded seals and 37 Pacific walruses to the total number of individuals recorded for these species. This proportional discrepancy in sightings versus individuals is further complicated by sightings in water versus sightings on ice. To avoid assumptive measures in subsequent analyses (e.g. detection rates, distribution, behavior), all unidentified large pinniped sightings were included in the *Seals* section where they constitute only two percent of the total number of useable sightings for 2006–2007.

TABLE 3.12. Useable seal sightings (number of individuals) recorded in water and on ice in the Chukchi Sea during 2006 and 2007 vessel operations.

Species	**Source Vessels**		**Support Vessels**		**Annual Totals**	
	2006	**2007**	**2006**	**2007**	**2006**	**2007**
Seals and Sea Lions in Water						
Bearded Seal	11 (16)	1 (1)	205 (241)	33 (37)	***216 (257)***	***34 (38)***
Ringed and Spotted Seals[a]	146 (152)	10 (10)	1329 (1487)	164 (183)	***1475 (1639)***	***174 (193)***
Steller Sea Lion	0	0	0	1 (1)	***0***	***1 (1)***
Unidentified Pinnipeds	12 (13)	3 (4)	8 (8)	11 (14)	***20 (21)***	***14 (18)***
Seals on Ice[b]						
Bearded Seal	0	0	0	3 (16)	***0***	***3 (16)***
Ribbon Seal	1 (1)	0	0	0	***1 (1)***	***0***
Ringed and Spotted Seals[a]	7 (9)	0	4 (5)	6 (72)	***11 (14)***	***6 (72)***
Unidentified Pinnipeds	1 (1)	0	0	0	***1 (1)***	***0***
Total Seals and Sea Lions	***178 (192)***	***14 (15)***	***1546 (1741)***	***218 (323)***	***1724 (1933)***	***232 (338)***

[a] Includes all records of ringed, spotted, and unidentified seals.

[b] There were no sea lions sighted on ice

Detection Rates by Season.—Seasonal patterns in seal detection rates were similar between 2006 and 2007, although overall detection rates were lower in 2007. Seal detection rates were higher in summer and fall from support vessels than source vessels during both 2006 and 2007. Summer and fall detection rates for both vessel types were greater in 2006 than 2007 (Fig. 3.29).

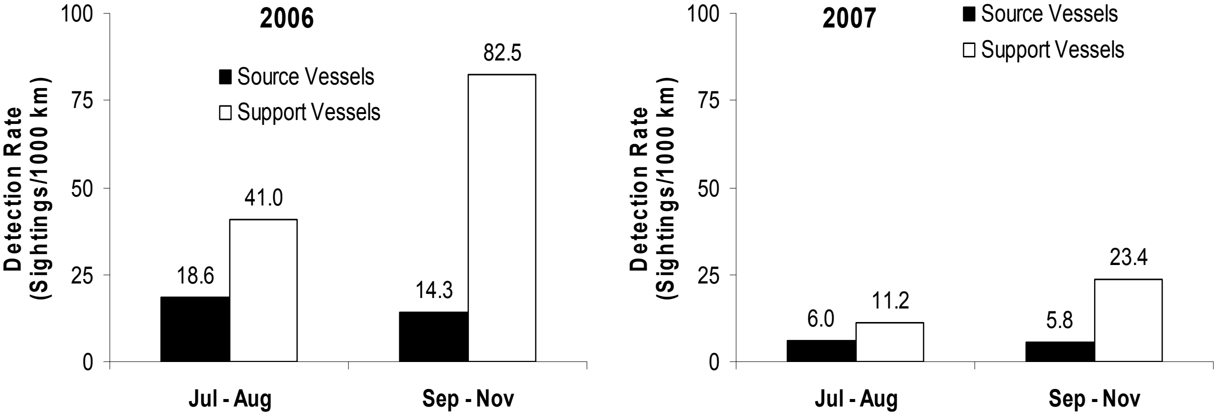

FIGURE 3.29. Detection rates from useable seal sightings by season recorded during 2006 and 2007 Chukchi Sea vessel operations.

Detection Rates by Seismic State.—The pattern in seal sighting rates for seismic states was similar to the seasonal pattern described above for source and support vessels in 2006 and 2007. Seal detection rates were higher from support than from source vessels during seismic and non–seismic periods in both 2006 and 2007. Overall detection rate rates were much lower from both vessel types and for both seismic states in 2007 compared to 2006 (Fig. 3.30).

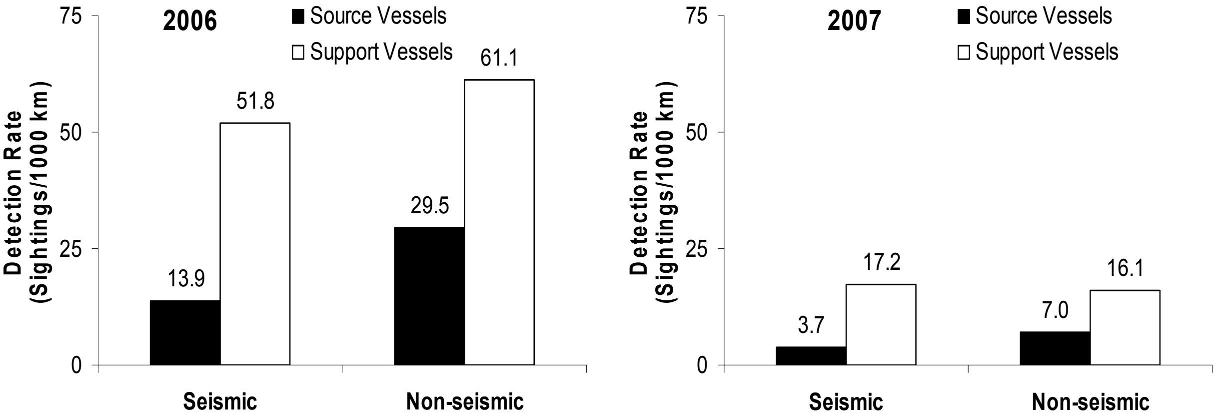

FIGURE 3.30. Detection rates from useable seal sightings by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations.

In addition to comparing seal detection rates between seismic and non-seismic periods based on useable data from source and support vessels, seismic and non-seismic detection rates in 2007 were also compared among various vessel types based on useable vs. all data (i.e., useable and non-useable data combined; Table 3.13). This was done to determine what effect the use of non-useable data may have on calculations of seal detection rates. For this analysis seal detection rates were calculated from the source vessel (*Gilavar*), from all support vessels combined, and from support vessels during the periods when they operated as chase vessels for the *Gilavar*. Chase vessel activities were concentrated within a few km of the *Gilavar* allowing for a comparison the two vessel types operating in the same area. Non-chase support vessels operated over a much wider area and were often not in the same area of the Chukchi Sea as the *Gilavar*.

Seal detection rates based on all data combined were lower than detection rates based on useable data for both seismic and non-seismic periods. This would be the expected result since overall sighting conditions based on useable data were better than conditions that include non-useable data. Seal detection rates from source vessels were higher during non-seismic than seismic periods based on both useable data and all data combined suggesting possible localized avoidance of the seismic vessel. No clear pattern was evident when comparing seal detection rates for non-seismic periods for the various vessel types based on useable data or all data combined. However seal detection rates were much higher from support and chase vessels than from the *Gilavar*. The trend in this analysis was similar to that of the previous analysis based solely on useable data (Fig. 3.30).

TABLE 3.13. Seal detection rates (sightings/1000km of trackline) from the source vessel (*Gilavar*), all support vessels, and all chase vessels during seismic and non-seismic periods in the Chukchi Sea 2007 based on useable data and all data (useable and non-useable) combined. Bold figures indicate values base on <500 km of effort.

	Seal Detection Rate			
	Useable Data		All Data	
	Seismic	Non-seismic	Seismic	Non-seismic
Source Vessel	3.7	7.0	1.5	5.1
All Support Vessels	17.2	16.1	15.0	13.5
Chase Vessels	17.4	23.3	15.6	20.0

Distribution

Initial sightings relative to vessels.—The bearing and distance to seals when first detected were determined for all useable sightings (Figs. 3.31–3.34). Bearing and distance were calculated from the airgun array for sightings from the source vessels and from the observer station for sightings from the support vessels. Sightings were fairly evenly distributed between the forward quarters of the vessels, where observers concentrated their effort.

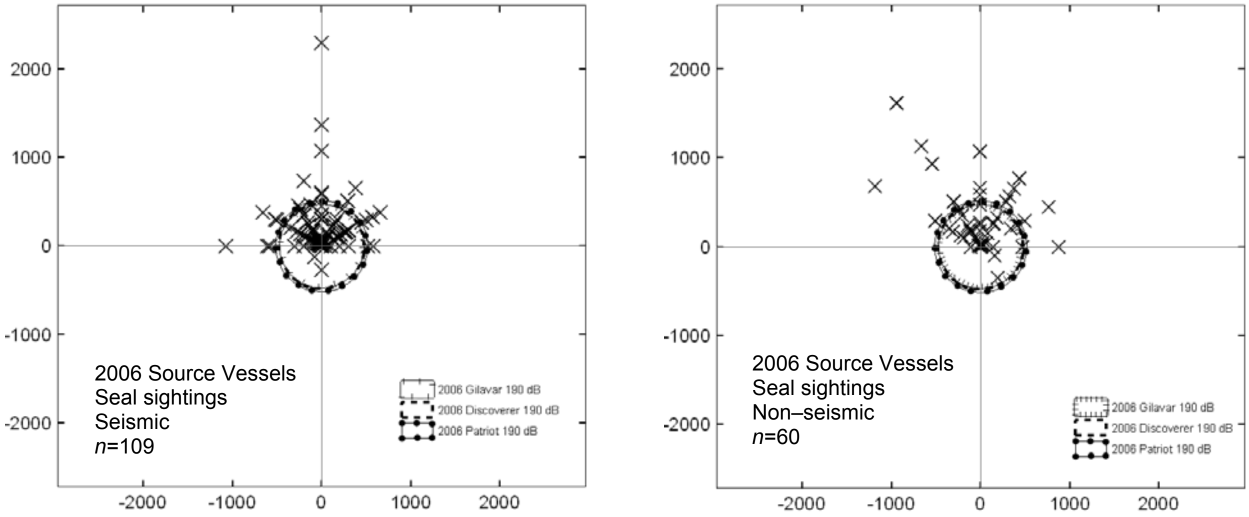

FIGURE 3.31. Relative locations of useable initial seal sightings from the source vessels during 2006 seismic surveys in the Chukchi Sea. The 190 dB sound level radii of the full airgun arrays are displayed for each of the source vessels (*Methods* section). The locations indicate distance (m) from the airgun array aft of the observer. All sightings are of animals in the water. The distance between tick marks (1000 m) = 0.6 mi.

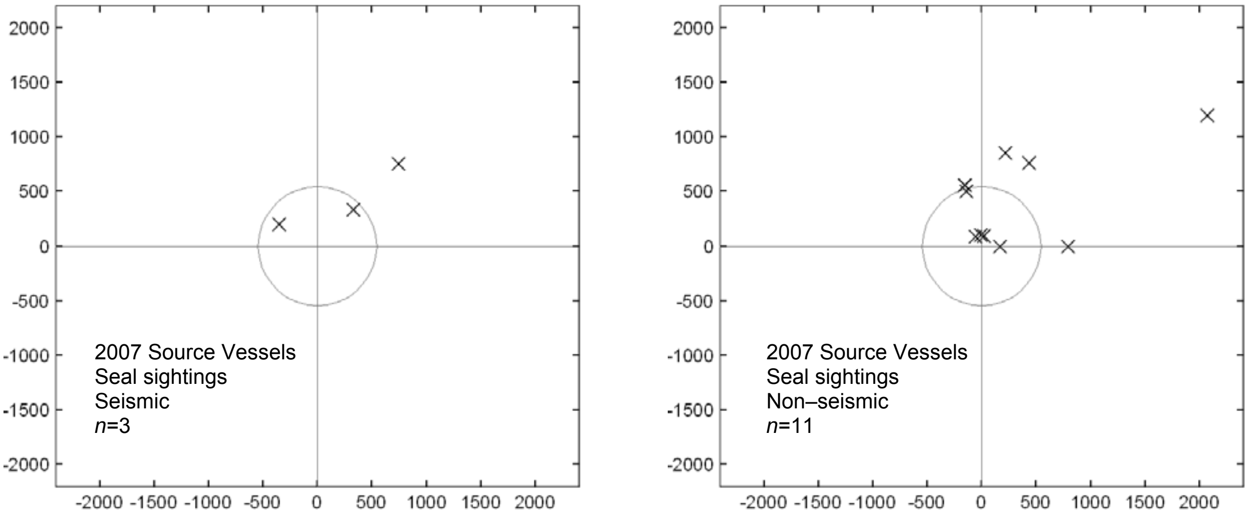

FIGURE 3.32. Relative locations of useable initial seal sightings from the source vessel in the Chukchi Sea, 2007. The 190 dB sound level radius is displayed (550 m or 602 yd). The sighting locations indicate distance (m) from the airgun array located 300 m (328 yds) aft of the observer station. All sightings are of animals in the water. The distance between x and y axis tick marks (500 m) = 0.3 mi.

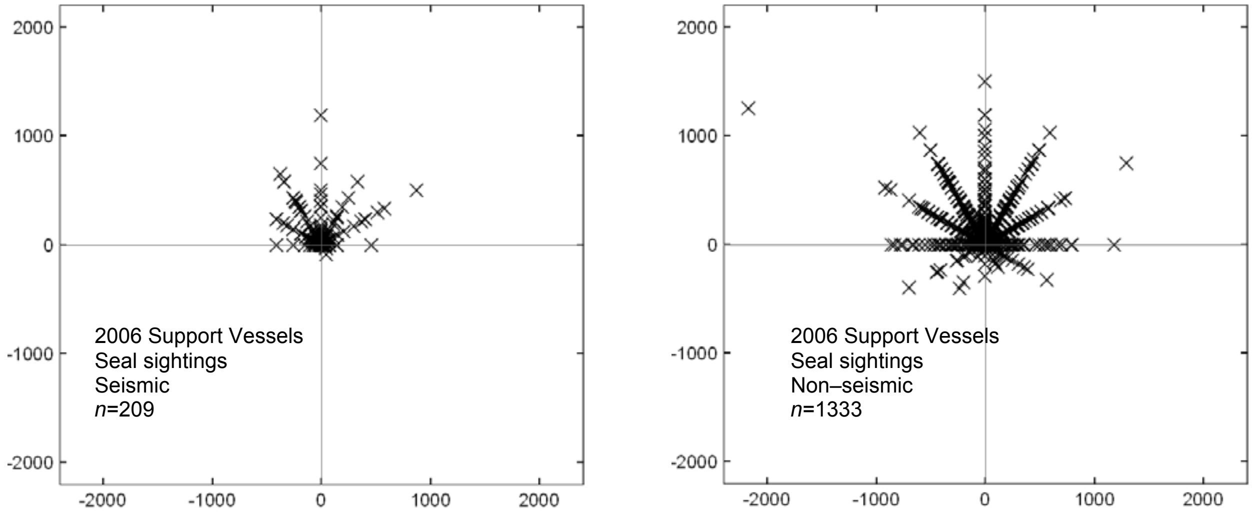

FIGURE 3.33. Relative locations of useable initial seal sightings from support vessels in the Chukchi Sea, 2006. Locations indicate distance (m) from the observer station; all sightings are of animals in the water. The distance between x and y axis tick marks (1000 m) = 0.6 mi.

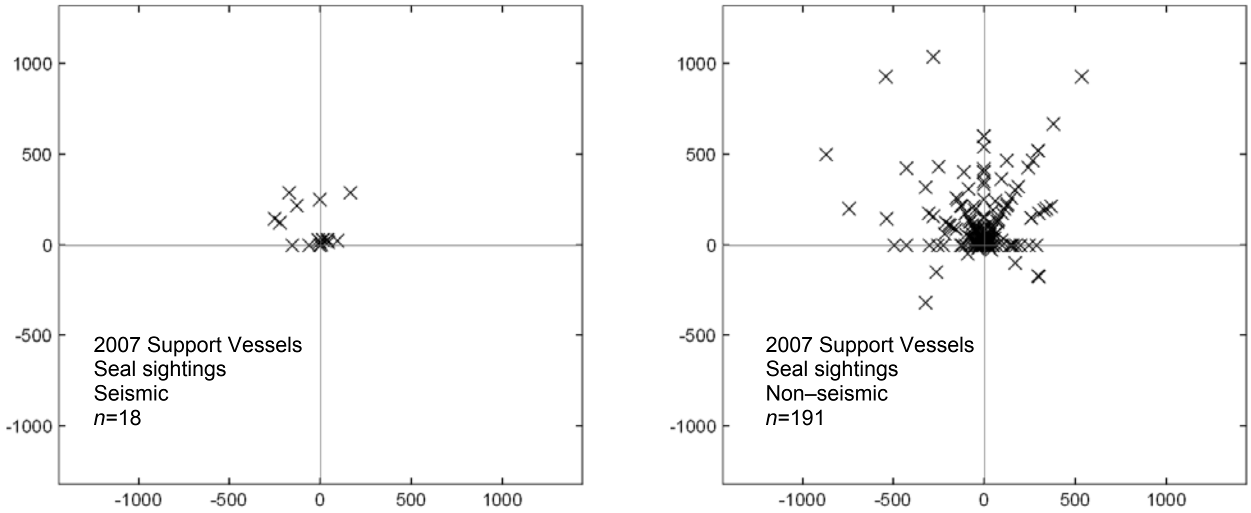

FIGURE 3.34. Relative location useable initial seal sightings from support vessels in the Chukchi Sea, 2007. Locations indicate distance (m) from the observer station; all sightings are of animals in the water. The distance between x and y axis tick marks (500 m) = 0.3 mi.

Closest Point of Approach.—In 2006, seals approached both source and support vessels more closely during seismic than non–seismic periods (Table 3.14). On average, the seal CPA from source vessels was over three times greater than the CPA from support vessels in 2006 (Table 3.14).

In general, CPAs in 2007 were similar to those in 2006, though the low number of seal sightings during seismic periods in 2007 (*n*=21 sightings) make comparisons difficult. Average seal CPA by vessel type and seismic state were similar between years (Table 3.14).

TABLE 3.14. Comparison of seal CPA distances by seismic period from useable sightings aboard source and support vessels during 2006 and 2007 Chukchi Sea vessel operations.

Effort Category	**Mean CPA[a] (m)**	**s.d.**	**Range (m)**	***n***
2006				
Source Vessels Seismic	557	313	30-2592	*109*
Source Vessels Non-seismic	788	433	301-2130	*69*
Source Vessels Mean	***647***	***380***	***30-2592***	***178***
Support Vessels Seismic	123	150	2-1011	*209*
Support Vessels Non-seismic	192	219	1-2500	*1337*
Support Vessels Mean	***182***	***212***	***1-2500***	***1546***
2007				
Source Vessels Seismic	570	164	435-753	*3*
Source Vessels Non-seismic	640	623	161-2434	*11*
Source Vessels Mean	***626***	***557***	***161-2434***	***14***
Support Vessels Seismic	129	120	10-335	*18*
Support Vessels Non-seismic	221	270	5-1500	*200*
Support Vessels Mean	***213***	***262***	***5-1500***	***218***

[a] CPA = *Closest Point of Approach*. For source vessels this value is the marine mammal's closest point of approach to the airgun array, for support vessels this value is the marine mammal's closest point of approach to the MMO/vessel.

Distance from Ice Detection Rates.—Seal detection rates during 2006 Chukchi Sea operations were higher in areas with ice and near ice than in areas without ice or far from ice (Fig. 3.35). In general, this trend was evident for both vessel groups operating in the Chukchi Sea in 2006. The same trend was observed in the 2007 data, though seal detection rates were much lower overall (Fig. 3.35). Also, the correlation between increased seal detection rates with increased proximity to ice was much more pronounced in 2006 when ice cover was greater in and around the study area.

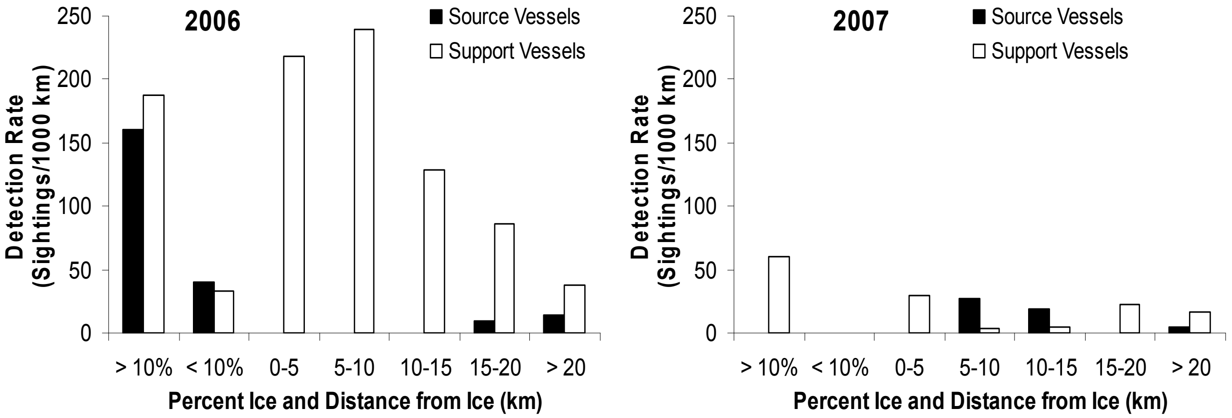

FIGURE 3.35. Detection rates from useable seal sightings by percent ice and distance from ice recorded during 2006 and 2007 Chukchi Sea vessel operations.

Distance from Shore Detection Rates.—Assessing differences in distance of sightings from shore between vessel types was difficult due to a lack of nearshore effort by source vessels in both 2006 and 2007. Detection rates from support vessels in 2006, however, were over two times greater in nearshore areas (>25 km or 15.5 mi from shore) than in areas farther offshore. Patterns were similar in 2007, though fewer seals were sighted overall and the difference between detection rates by distance from shore for support vessels was less than observed the previous year (Fig. 3.36).

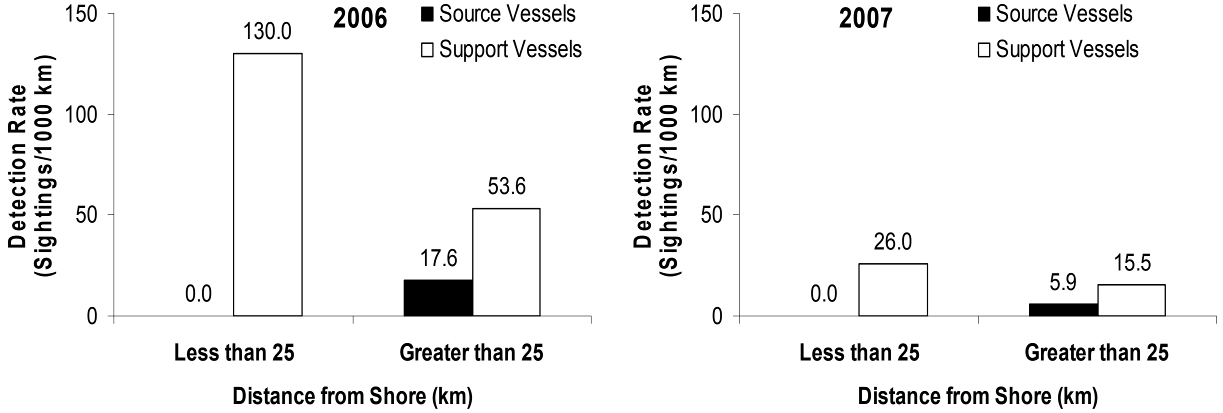

FIGURE 3.36. Detection rates from useable seal sightings by distance from shore recorded during 2006 and 2007 Chukchi Sea vessel operations.

Behavior

Movement.—The most consistently observed initial movement of seals recorded by MMOs on source vessels during seismic periods was swim away in 2006. Swim away was also observed frequently from source vessels during seismic periods in 2007, but most movement was classified as unknown. MMOs on support vessels during seismic periods in 2006 reported no movement most frequently for seals, followed by swim away and neutral movement. In 2007, swim away comprised ~70% of the seal movements recorded from support vessels during seismic period. Smaller numbers of seals were recorded as having neutral movement or were swimming toward the vessel (Fig. 3.37).

During non–seismic periods from source vessels in 2006, the predominant movement of seals was recorded as neutral or swim away which comprised ~80% of the recorded observations. During 2007, records of initial movement were distributed fairly evenly among all movement categories as recorded by MMOs during non–seismic periods aboard both source and support vessels. During non–seismic periods from support vessels in 2006, no movement, neutral, and swim away were the most common movement recorded by observers (Fig. 3.37).

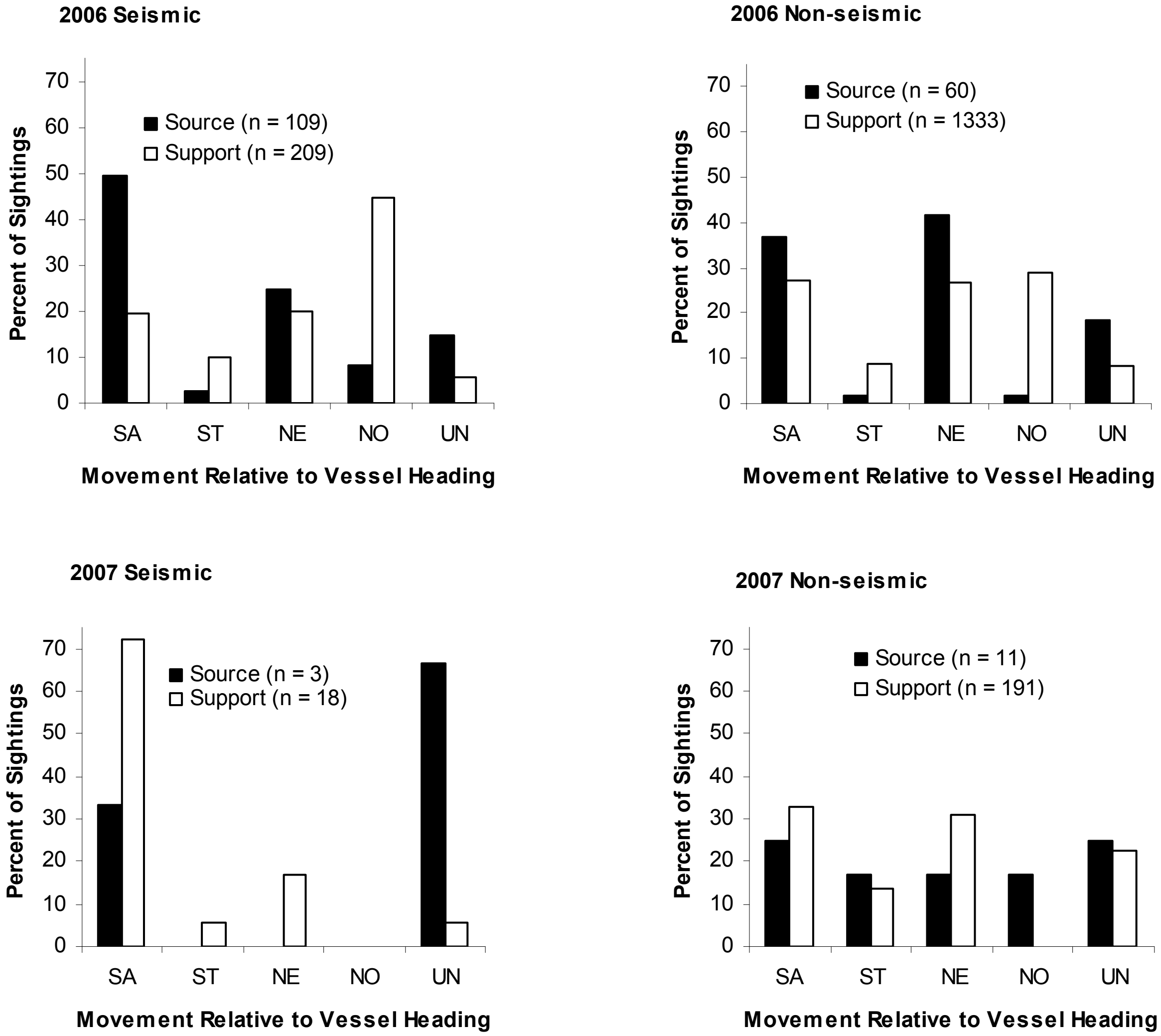

FIGURE 3.37. Percent of movement relative to vessels for useable seal sightings by seismic state for 2007 and 2006 Chukchi Sea survey operations. Sightings do not include seals hauled out of water. SA = Swim Away, ST = Swim Toward, NE = Neutral, NO = None, UN = Unknown.

Initial Behavior.—Looking and swimming were the predominantly observed behaviors of seals on both support and source vessels, regardless of seismic state in 2006 (Fig. 3.38). Behavior trends were slightly different in 2007. In addition to looking and swimming, diving was a common behavior during seismic periods. In contrast, surface active behaviors were prevalent during non–seismic periods, though looking and swimming were also common (Fig. 3.38). Trends in 2007 behavior data should be interpreted with caution, however, due to a much smaller sample size, especially during seismic periods (*n*=21).

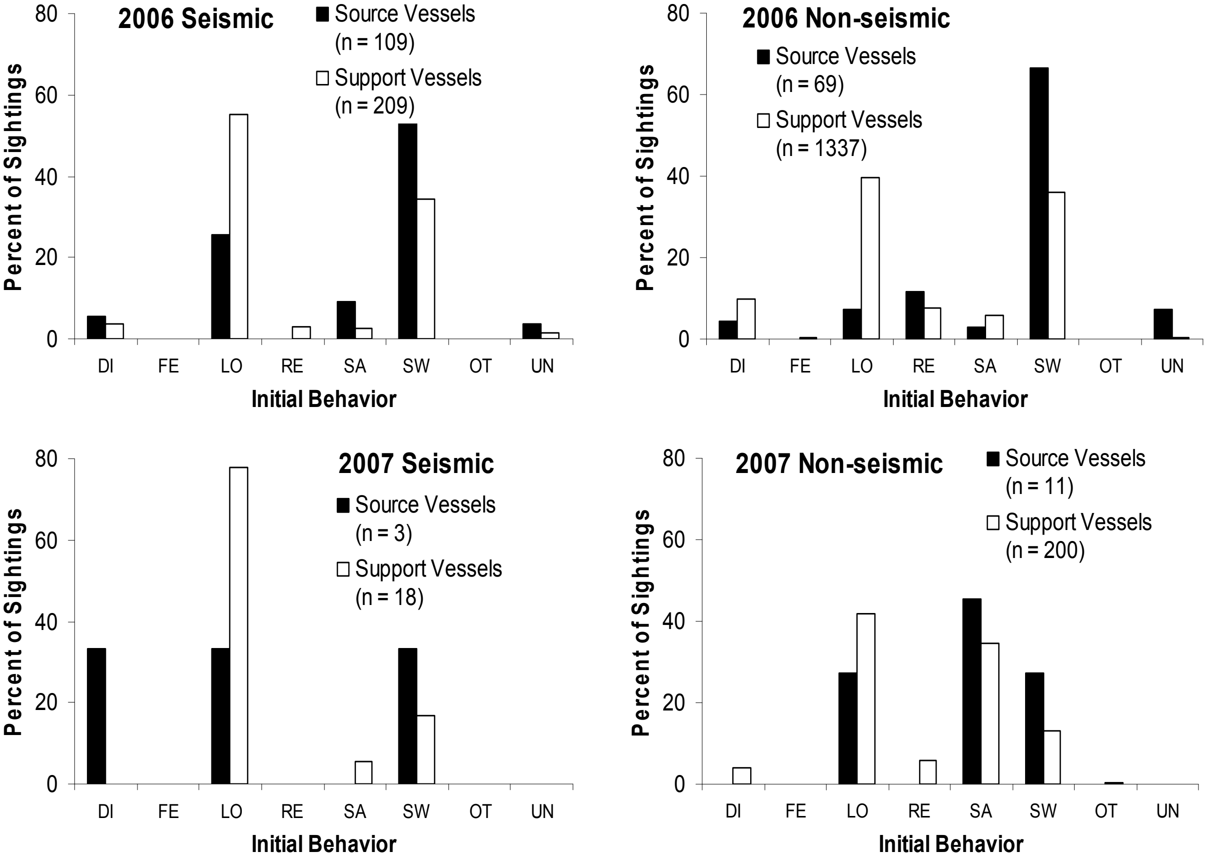

FIGURE 3.38. Percent of useable seal sightings performing initial behavior by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations. DI = Dive, FE = Feed, LO = Look, RE = Rest, SA = Surface Active, SW = Swim, OT = Other, UN = Unknown.

Reaction Behavior.—In general, a larger percentage of seals was observed reacting to vessels in 2006 than in 2007. Looking, changing direction or no reaction were the most commonly observed reactions during seismic periods in 2006 (Fig. 3.39). The percentage of seals showing no reaction was slightly higher during non–seismic than seismic periods in 2006. Looking and changing direction were also commonly observed reaction behaviors. In 2007, no reaction was by far the most prevalent reaction behavior from both source and support vessels, regardless of seismic state followed by looking, splashing and changing direction (Fig. 3.39).

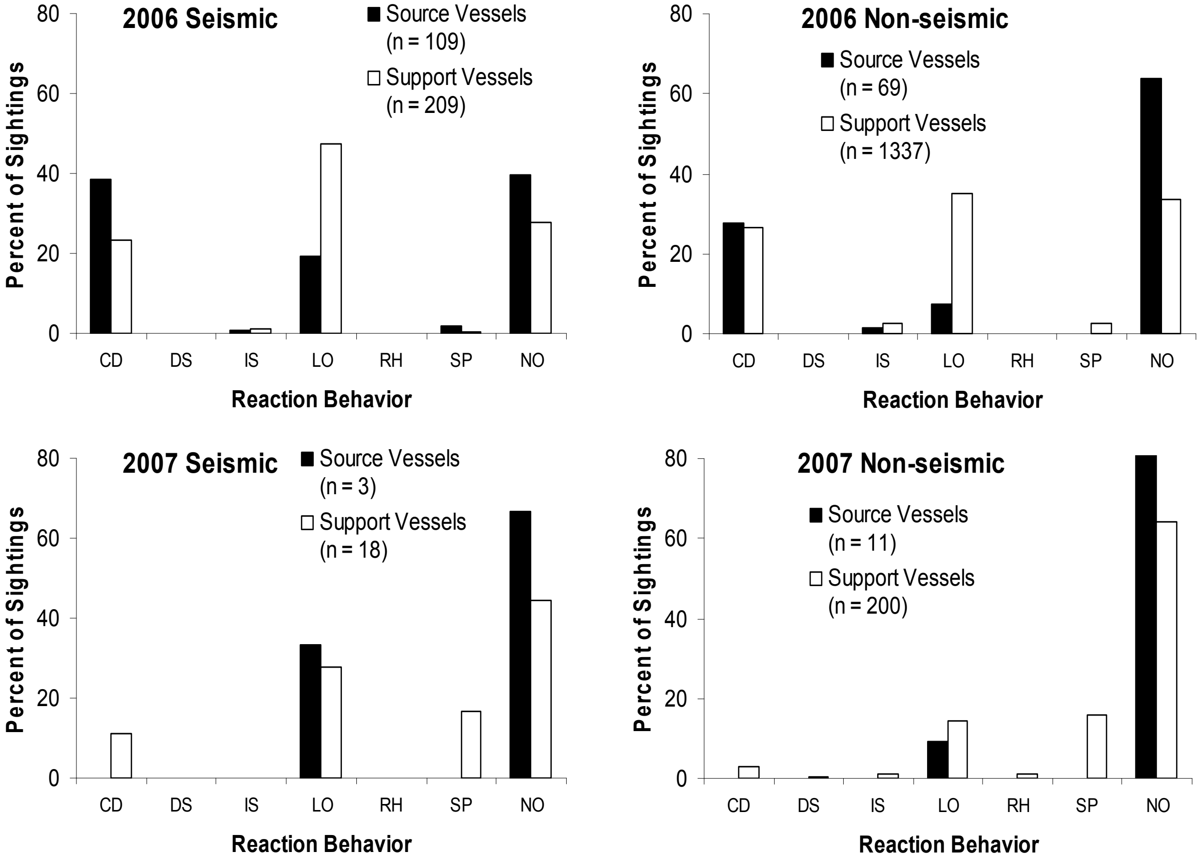

FIGURE 3.39. Percent of useable seal sightings that showed each reaction behavior by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations. CD = Change Direction, DS = Decrease Speed, IS = Increase Speed, LO = Look, RH = Rush (from ice or land into water), SP = Splash, NO = No Reaction.

Seal Detection Rates Relative to Received Sound Levels

If seals were avoiding seismic airguns, detection rates should decrease as received sound levels increase. No trend was observed when comparing seal detection rates from support vessels within 10 dB (rms) bins during seismic survey activities in the Chukchi Sea in 2007 (Table 3.15). However the amount of useable effort was low (<500 km or 311 mi) for most sound level categories above 120 dB rms (Table 3.15). In 2006, the amount of useable effort was greater than in 2007 for all sound level categories with the exception of 180–189 dB (rms). The seal detection rates within areas where received sound levels were <120 dB (rms) and in the 180–189 dB (rms) sound level category were higher than rates in other categories. The relatively high detection rate in the 180–189 dB (rms) sound level category in 2006 was based on a low amount of effort and should be viewed with caution.

TABLE 3.15. Number of detections, amount of useable effort (km), and detection rates (detections/ 1000 km) for seals observed from support vessels within received sound level distances during seismic periods in the Chukchi Sea during 2006 and 2007.

	2006			2007		
Received Sound Exposure Level (dB re1 µPa rms)	Number of Sightings	Useable Effort (km)	Detection Rate (sightings / 1000 km)	Number of Sightings	Useable Effort (km)	Detection Rate (sightings / 1000 km)
< 120	939	8139.5	115.4	44	2219.9	19.8
120 - 129	51	1565.1	32.6	6	552.7	10.9
130 - 139	69	2372.7	29.1	9	411.2	21.9
140 - 149	92	2311.0	39.8	9	439.7	20.5
150 - 159	32	2107.7	15.2	4	511.1	7.8
160 - 169	209	5162.2	40.5	3	160.5	18.7
170 - 179	79	1681.1	47.0	8	316.4	25.3
180 - 189	3	46.9	63.9	4	268.9	14.9

Probability of Seal Detection with Distance from Vessel

The effects of number of observers and Beaufort wind force were considered separately for vessels with observation platforms higher and lower than 12 meters (13 yards). For vessels with observation platforms higher than 12 m, the effective strip half–width (ESW) ranged from 115 m (126 yds) to 496 m (542 yds; Fig. 3.40). For vessels with observation platforms lower than 12 m, the ESW ranged from 109 m (119 yds) to 662 m (724 yds; Fig. 3.41). The ESW was expected to be directly related to the number of observers on watch and inversely related to Beaufort wind force. These trends were generally observed but in some cases unexpected results were found, perhaps influenced by sample size limitations. One example of an unexpected result came from the vessels with lower observation platforms, where during periods with Beaufort wind force 2–3, increasing the number of observers from one to two resulted in a decreased ESW by 2%, but increasing the number of observers from one to three increased ESW by 56% (Fig. 3.41). In this case, unequal sample sizes may have played a role (*n* = 345, 81, and 154 for one, two, and three observers, respectively).

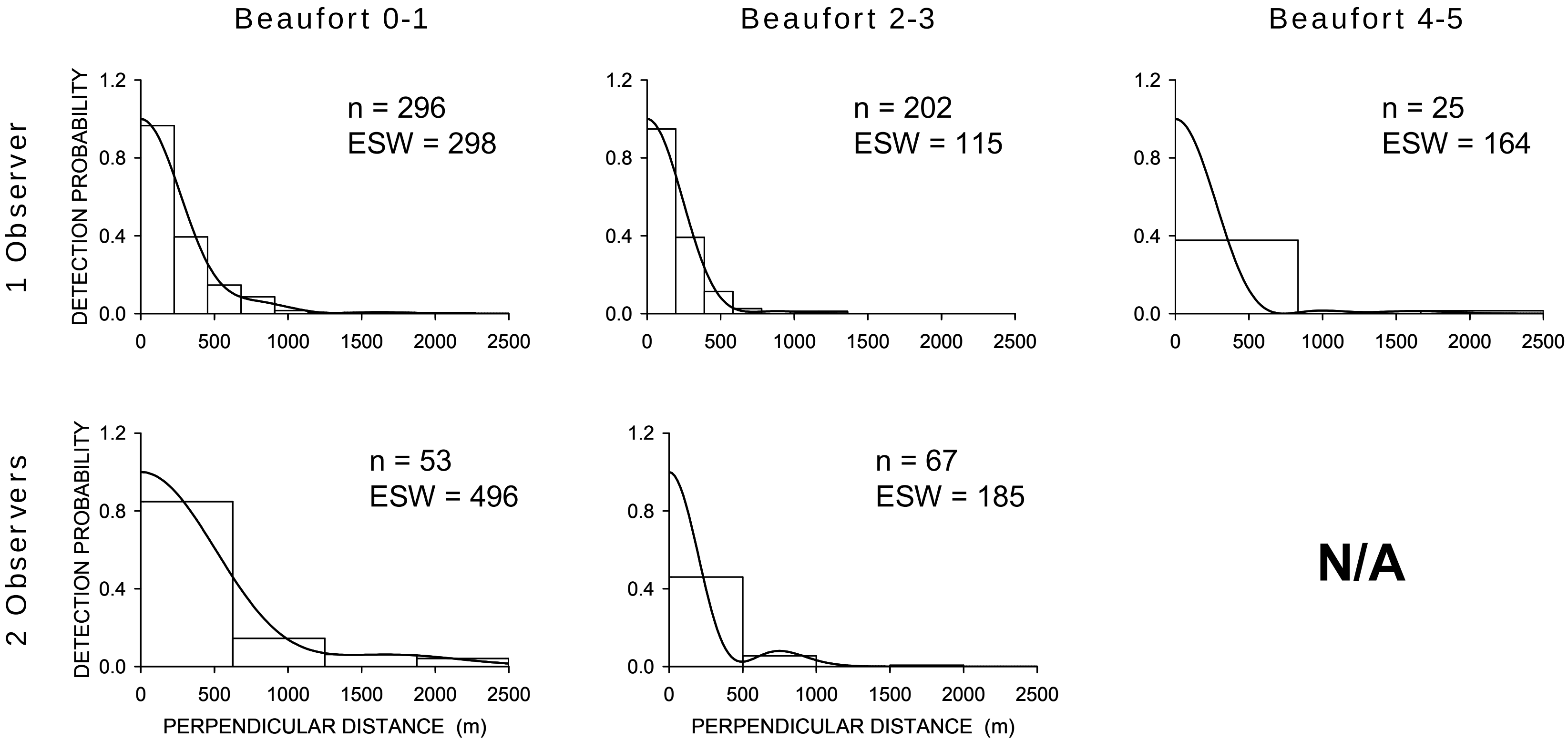

FIGURE 3.40. Effect of number of observers and Beaufort wind force on the detection probability of seals. Data considered in this analysis were collected on vessels with observation platforms 12.4 – 27.0 m in height and includes data collected outside of the Chukchi and Beaufort Sea study areas during 2006–07.

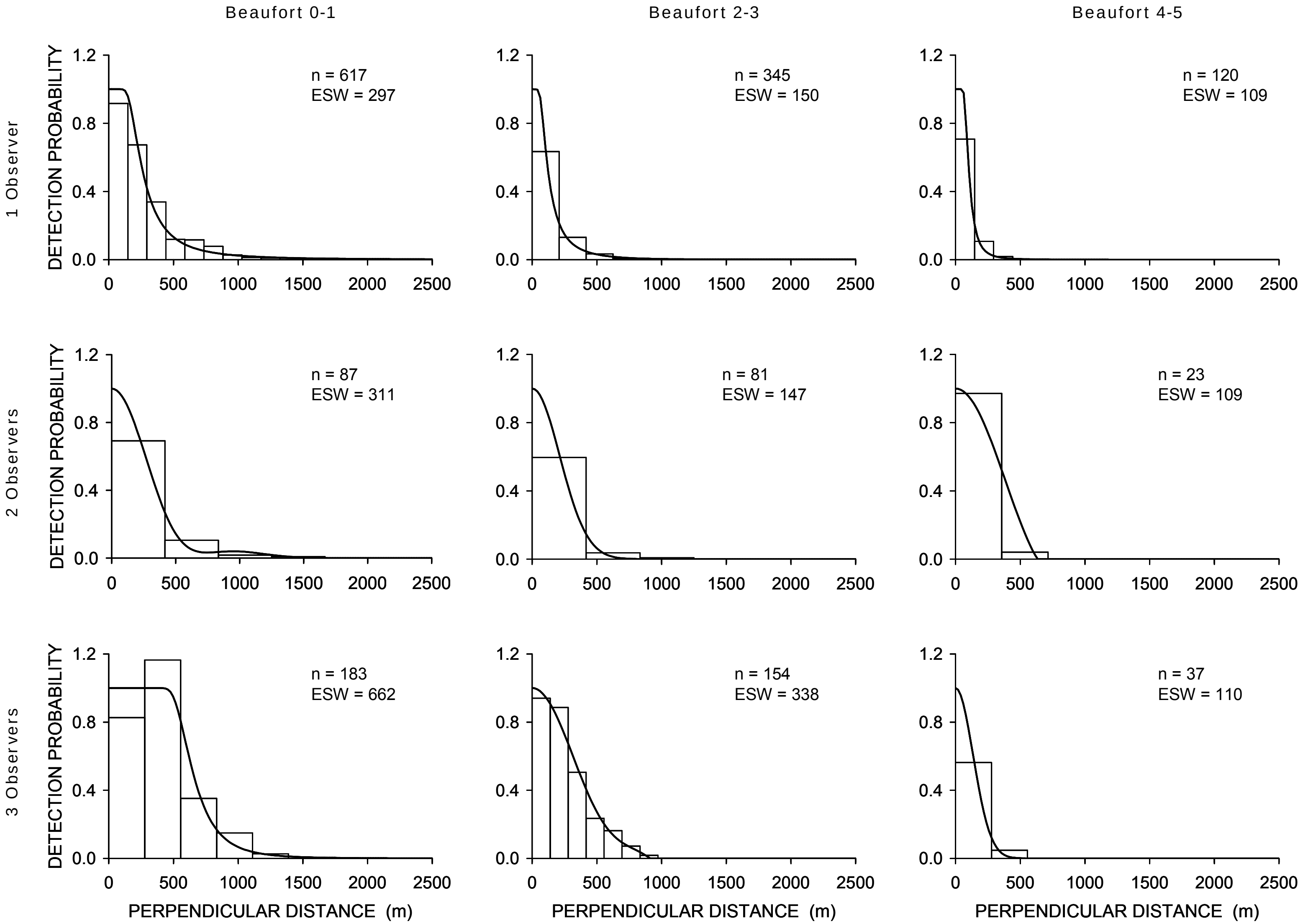

FIGURE 3.41. Effect of number of observers and Beaufort wind force on the detection probability of seals. Data considered in this analysis were collected on vessels with observation platforms 5.0 and 10.2 m in height and includes data collected outside of the Chukchi and Beaufort Sea study areas during 2006–07.

Estimated Number of Seals Potentially Ensonified

Estimates from direct observations.—The number of seals directly observed within the areas where received sound levels were ≥160 and 180 dB re 1 µPa (rms) provided a minimum estimate of the number of individuals potentially exposed to sounds at these levels. For this analysis, data were not filtered using the usability criteria outlined in the *Methods* section. Table 3.16 presents the number of seals exposed to received levels ≥ 160, 170, and 190 dB re 1 µPa (rms) in the Chukchi Sea during 2007. It is possible that some seals present within these areas were not detected by observers, and therefore these numbers are likely underestimates of the number of individuals ensonified.

TABLE 3.16. Total number of seals observed within the ≥160, 170, and 190 dB re 1 µPa (rms) radii of active seismic airguns in 2006 and 2007.

Received Sound Level (dB re1 µPa rms)	**Sightings(Individuals)**	
	2006	**2007**
≥160	674(709)	36(36)
≥170	299(313)	24(24)
≥190	59(61)	1(1)

Estimates Extrapolated from Density.—Table 3.17 presents seal density estimates that account for animals that were not detected by observers in 2007 due to sightability bias (refer to Appendix F for more detailed explanation of the methods used for determining densities). Insufficient data were available to calculate a seal density estimate for the summer period using seismic data, however summer seal density was estimated at 53.9 seals/1000 km^2 (310 mi^2) based on non–seismic period data. Fall seal density was estimated at 145.3 and 54.4 seals/1000 km^2 (310 mi^2) based on non–seismic and seismic periods, respectively. Lower density estimates during seismic periods suggest possible localized seal avoidance of seismic activity in 2007.

The estimated number of seals exposed to various sound levels during 2006 and 2007 seismic operation are shown in Tables 3.18 and 3.19. These values are from SOI’s 2007 operations 90–d report (Funk et al. 2008) and the 2006 operation JMP report (Funk et al. 2007). The amount of useable effort from vessels directly involved with seismic operations in the Chukchi Sea in 2007 was insufficient to calculate reliable density estimates. As an alternative, all daylight effort and sightings from these vessels were used to calculate the density estimates used in estimating seal exposures to various received sound levels (for details see Funk et al. 2008). During 2006, walruses and seals were combined to produce an overall pinniped density estimate. Non–seismic density estimates represent the number of animals that would have been exposed had they not shown localized avoidance behavior in response to the airguns or the vessels themselves.

TABLE 3.17. Seal density estimates based on data collected from source and support vessels during seismic and non–seismic periods in the Chukchi Sea, summer and fall 2007.

		No. individuals / 1000km^2		
		Summer	Fall	
Vessel Type	**Species**	**Non-seismic**	**Seismic**	**Non-seismic**
Source Vessels				
	Bearded Seal	0.0	4.7	0.0
	Spotted/Ringed Seal	14.1	9.7	36.2
	Unidentified Pinniped	10.2	0.0	0.0
	Source Vessel Total	**24.3**	**14.4**	**36.2**
Support Vessels				
	Bearded Seal	10.5	9.2	31.3
	Spotted/Ringed Seal	44.7	74.5	114.8
	Unidentified Pinniped	3.4	0.0	7.2
	Stellar Sea Lion	0.0	0.0	1.1
	Support Vessel Total	**58.7**	**83.6**	**154.4**
All Vessels				
	Bearded Seal	9.0	7.3	29.4
	Spotted/Ringed Seal	40.5	47.1	110.1
	Unidentified Pinniped	4.4	0.0	4.8
	Stellar Sea Lion	0.0	0.0	1.0
	All Vessel Total	**53.9**	**54.4**	**145.3**

- indicates less than 500 km of useable effort

Pinniped seasons in 2006 and 2007 were defined differently. In 2006, the "early season" was defined as the period before 28 Aug, the "mid–season" was from 28 Aug through 8 Oct, and the "late season" was from 9 Oct onward, whereas in 2007, the more general summer (Jun–Aug) and fall (Sep–Nov) season definitions were applied, as discussed above. In 2006, the data were partitioned by nearshore and offshore, whereas in 2007 partitioning was not possible due to insufficient data. Because of these differences it was difficult to make direct comparisons of the numbers of pinnipeds exposed to various received sound levels in 2006 and 2007.

In 2006, an estimated 8532 and 4049 pinnipeds (including walrus) were exposed to received levels of sound ≥ 170 and 180 dB (rms), respectively, based on data collected during non–seismic periods. In 2007, an estimated 291 and 97 seals were exposed to sound at the same levels. Because these estimates were derived from non–seismic period data, they are considered conservative in that they do not account for behavioral reactions of animals moving away from the seismic survey activities. The difference in the numbers of estimated pinniped exposures to received sound levels between years was due to the greater amount of seismic survey activity from three source vessels in 2006 compared to the single source vessel in 2007. Additionally, overall pinniped densities in 2006 may have been higher than in 2007 due to higher ice coverage in the project area in 2006.

TABLE 3.18. Estimated numbers of pinniped individuals ensonified at different levels, and average number of exposures per individual in both the nearshore and offshore regions, using ***(A)*** Non–seismic densities, and ***(B)*** Seismic densities, from useable[a] data in 2006.

		Nearshore		**Offshore**		***Total***	
	Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures / Individual**	**Individuals**	**Exposures / Individual**	**Individuals**	**Exposures / Individual**
Pinnipeds in Water							
A. Non-seismic density							
Early season	**≥160**	0	0.0	1088	6.0	1088	6.0
	≥170	0	0.0	625	5.4	625	5.4
	≥180	0	0.0	353	5.1	353	5.1
	≥190	0	0.0	278	3.0	278	3.0
Mid-season	**≥160**	0	0.0	3710	16.6	3710	16.6
	≥170	0	0.0	2576	10.4	2576	10.4
	≥180	0	0.0	1632	5.2	1632	5.2
	≥190	0	0.0	1002	2.5	1002	2.5
Late season	**≥160**	34	1.0	10,005	1.5	10,039	1.5
	≥170	14	1.0	5317	1.3	5331	1.3
	≥180	5	1.0	2059	1.1	2064	1.1
	≥190	2	1.0	627	1.1	629	1.1
All seasons	**≥160**	34	1.0	14,803	5.6	***14,837***	***5.6***
	≥170	14	1.0	8518	4.4	***8532***	***4.3***
	≥180	5	1.0	4044	3.1	***4049***	***3.1***
	≥190	2	1.0	1907	2.1	***1909***	***2.1***
B. Seismic density [b]							
Early season	**≥160**	0	0.0	2986	6.0	2986	6.0
	≥170	0	0.0	1715	5.4	1715	5.4
	≥180	0	0.0	968	5.1	968	5.1
	≥190	0	0.0	762	3.0	762	3.0
Mid-season	**≥160**	0	0.0	8,635	16.6	8,635	16.6
	≥170	0	0.0	5996	10.4	5996	10.4
	≥180	0	0.0	3799	5.2	3799	5.2
	≥190	0	0.0	2332	2.5	2332	2.5
Late season	**≥160**	110	1.0	13,432	1.5	13,542	1.5
	≥170	45	1.0	7139	1.3	7184	1.3
	≥180	16	1.0	2764	1.1	2780	1.1
	≥190	6	1.0	842	1.1	847	1.1
All seasons	**≥160**	110	1.0	25,053	7.2	***25,163***	***7.2***
	≥170	45	1.0	14,850	5.4	***14,895***	***5.4***
	≥180	16	1.0	7531	3.7	***7547***	***3.7***
	≥190	6	1.0	3936	2.3	***3942***	***2.3***

[a] See *Useability Criteria* in *Methods* section in this Chapter.

[b] The offshore seismic density was used in both the nearshore and offshore calculations.

TABLE 3.19 Estimated numbers of individual seals exposed to received sound levels ≥160, 170, 180, and 190 dB re 1 µPa (rms) and average number of exposures per individual within the Chukchi Sea during both the summer and fall survey periods of 2007. Requested number of takes for the Chukchi Sea is also shown. Estimates are based on "corrected" densities of seals calculated from daylight MMO watch effort, using seismic and non–seismic densities.

	Non-seismic		Seismic	
Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures per Individual**	**Individuals**	**Exposures per Individual**
Summer Seals				
≥160	263	18.5	118	18.5
≥170	169	13.4	76	13.4
≥180	127	8.9	57	8.9
≥190	60	3.9	27	3.9
Fall Seals				
≥160	176	13.7	96	13.7
≥170	121	9.7	66	9.7
≥180	86	7.0	47	7.0
≥190	37	3.4	20	3.4
Total Seals				
≥160	439	26.0	214	26.0
≥170	291	17.7	143	17.7
≥180	213	11.5	104	11.5
≥190	97	3.6	47	3.6

* Totals may not add up to sum of summer and fall values due to rounding

Pacific Walruses

Sightings

Total Sightings.—MMOs recorded 127 useable Pacific walrus sightings comprised of 1094 individuals during 2006 Chukchi Sea vessel operations. Over 80% of walrus sightings and 96% of individuals were recorded from support vessels (Table 3.20). The majority of 2006 Pacific walrus sightings and individuals were in water as opposed to on ice (Table 3.20), and Pacific walrus sightings comprised only 14% of all useable marine mammal sightings in 2006.

By comparison, useable Pacific walrus sightings during 2007 Chukchi Sea vessel operations accounted for over half of all useable marine mammal sightings and nearly 90% of the total number of individual animals recorded by MMOs. Observers documented 334 useable sightings of an estimated 2955 individuals in 2007 (Table 3.20). Nearly half of the 2007 Pacific walrus sightings (n = 143) were recorded during a 24–hour period from the *Gilavar* on 24 Aug (prior to the start of 2007 seismic survey operations). It was suspected that this “patch” of animals was moving from the pack ice towards shore and passed through the prospect area. The support vessel was transiting to Barrow for a crew change on 24 Aug and did not encounter as many walruses. Only seven of the 334 Pacific walrus sightings were of animals on ice, but these seven sightings comprised 1418 of the 2955 individuals, or ~48%, of the total walruses recorded in 2007 (Table 3.20).

TABLE 3.20. Useable Pacific walrus sightings (number of individuals) recorded in water versus on ice during 2006 and 2007 Chukchi Sea vessel operations.

Species and Location	Source Vessels		Support Vessels		Annual Totals	
	2006	2007	2006	2007	2006	2007
Pacific Walruses in Water	22 (30)	206 (1155)	96 (966)	121 (382)	***118 (996)***	***327 (1537)***
Pacific Walruses on Ice	2 (10)	1 (404)	7 (88)	6 (1014)	***9 (98)***	***7 (1418)***
Total Pacific Walruses	***24 (40)***	***207 (1559)***	***103 (1054)***	***127 (1396)***	***127 (1094)***	***334 (2955)***

Detection Rates by Season.—Pacific walrus detection rates in summer 2006 were relatively low and comparable between source and support vessels. The Pacific walrus detection rate in the fall of 2006 from source vessels was slightly higher than the summer value, while the detection rate recorded from support vessels during fall was more than twice the summer rate. Overall, Pacific walrus detection rates in 2006 were similar across seasons and vessel groups when compared with 2007 results (Fig. 3.42).

Pacific walrus detection rates from source vessels in 2007 were nearly 10 times higher during the summer compared to fall (Fig. 3.42), though this was due to the 24 Aug sighting event. If the source vessel 24 Aug walrus sightings are omitted from analyses, the detection rate in summer falls by 72% but still is more than five times the detection rate recorded from support vessels during summer of 2007. Pacific walrus detection rates from support vessels were nearly the same during summer compared to fall for the 2007 Chukchi Sea survey. Detection rates in fall were similar between vessel groups (Fig. 3.42).

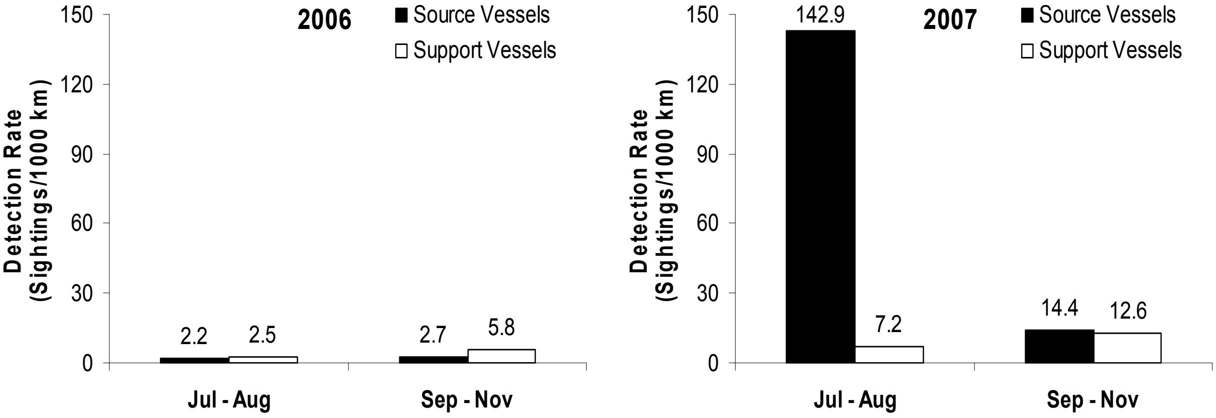

FIGURE 3.42. Detection rates from useable Pacific walrus sightings by season recorded during 2006 and 2007 Chukchi Sea vessel operations.

Detection Rates by Seismic State.—Pacific walrus detection rates during 2006 Chukchi Sea seismic operations were low from source vessels and no walruses were detected from support vessels during seismic periods. Pacific walrus detection rates during non–seismic periods were greater than during seismic period rates and were similar between vessel groups (Fig. 3.43).

Pacific walrus detection rates during seismic operations in 2007 were slightly higher from support vessels than source vessels (Fig. 3.43). Non–seismic detection rates, however, were nearly 20 times higher from source than support vessels, and this resulted from the *Gilavar's* 24 Aug sighting event. If the *Gilavar's* 143 Pacific walrus sightings from 24 Aug are omitted from non–seismic detection rate calculations the rate falls by 72%, but is still more than four times greater than the non–seismic rate recorded from support vessels. Support vessel MMOs detected ~five times as many Pacific walruses during seismic compared with non–seismic periods in 2007 (Fig. 3.42).

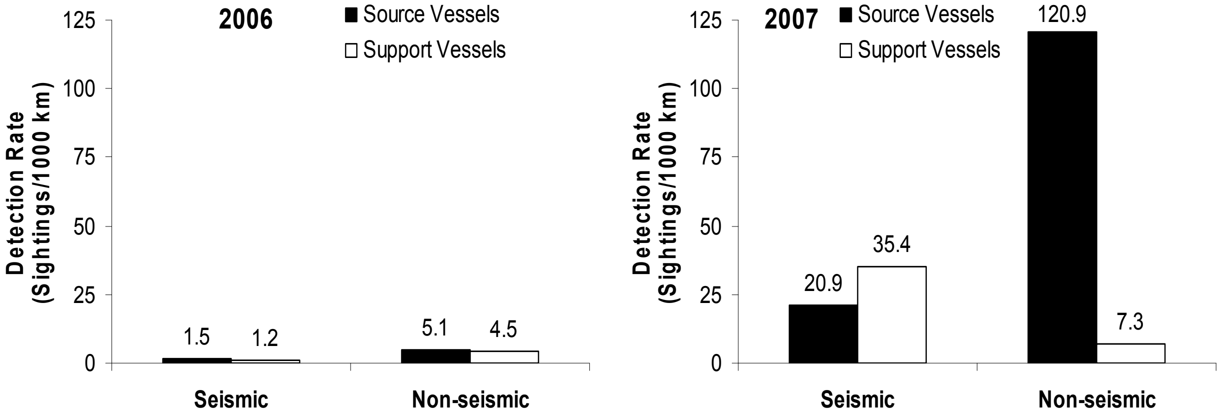

FIGURE 3.43. Detection rates from useable Pacific walrus sightings by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations.

Distribution

Initial sightings relative to vessels.—The bearing and distance of Pacific walruses were determined for all useable initial sightings. Bearing and distance were calculated from the airgun array for sightings from the source vessels and from the observer station for sightings from the support vessels (Figs. 3.44–3.47). Although the 190 dB radii were applied in 2006 as the safety zone around active airgun arrays for Pacific walruses, the ≥180 dB sound level was employed in 2007 (as directed by USFWS). Therefore, the 190 dB sound level radii are displayed for the 2006 plots and the 180 dB radius is displayed for the 2007 plots (Figs. 3.44–3.45).

Pacific walruses were observed distributed more tightly around the source vessel during seismic periods in 2006 than during non–seismic periods. This suggests that Pacific walruses may not have avoided areas of seismic activity, although the number of sightings was relatively low (i.e., n = 22). Overall, sightings of Pacific walruses were fairly evenly distributed between the forward quarters of the vessels, where the observers concentrated their effort.

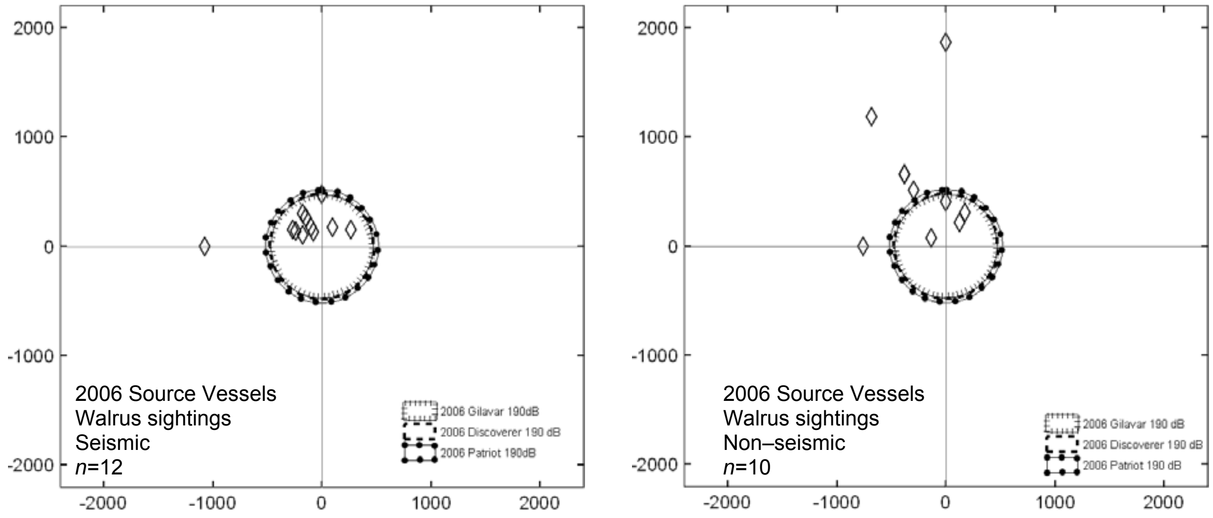

FIGURE 3.44. Relative locations of useable initial Pacific walrus sightings from the source vessels during 2006 seismic surveys in the Chukchi Sea. The 190 dB sound level radii of the full airgun arrays are displayed for each of the source vessels (*Methods* section). The locations indicate distance (m) from the airgun array, aft of the observer. All sightings are of animals in the water. The distance between tick marks (1000 m) = 0.6 mi.

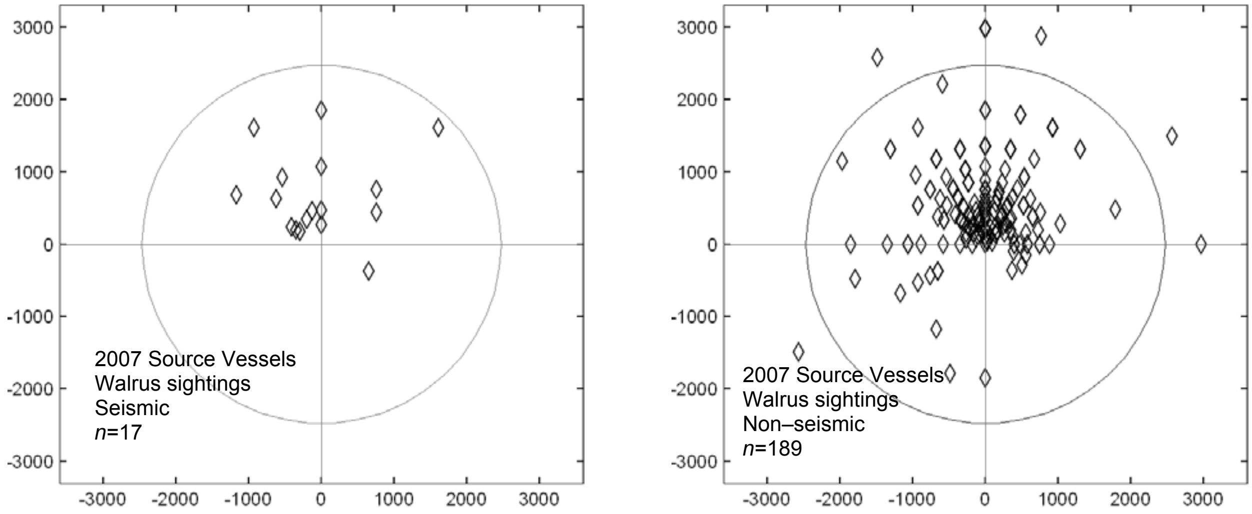

FIGURE 3.45. Relative location of useable initial Pacific walrus sightings from the source vessel in the Chukchi Sea, 2007. The 180 dB sound level radius is displayed (2.47 km or 1.5 mi). The locations indicate distance (m) from the airgun array location 300 m (328 yd) aft of the observer. All sightings are of animals in the water. The distance between x and y axis tick marks (1000 m) = 0.6 mi.

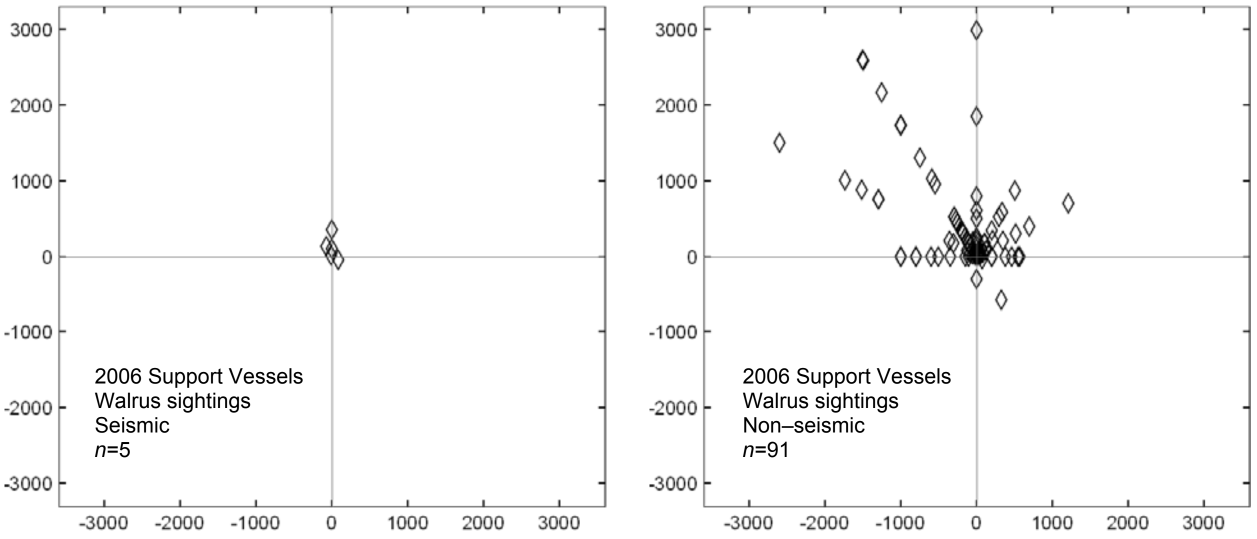

FIGURE 3.46. Relative locations of useable initial Pacific walrus sightings from support vessels in the Chukchi Sea, 2006. The locations indicate distance (m) from the observer station. All sightings are of animals in the water. The distance between x and y axis tick marks (1000 m) = 0.6 mi.

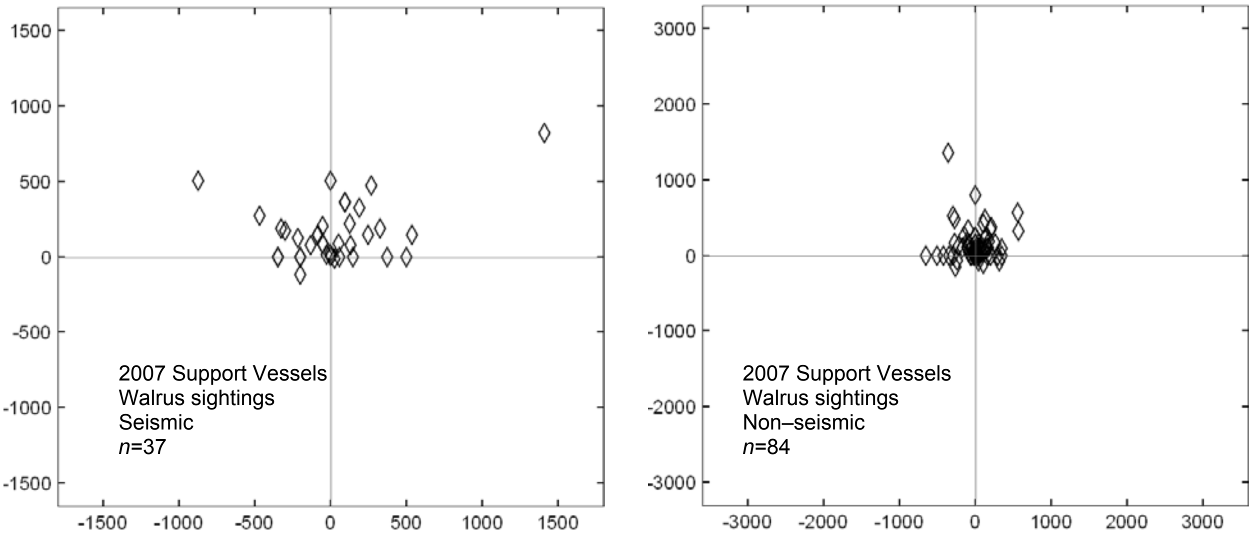

FIGURE 3.47. Relative location useable Pacific walrus sightings from support vessels in the Chukchi Sea, 2007. The locations indicate distance (m) from the observer station. All sightings are of animals in the water. The distance between x and y axis tick marks (1000 m) = 0.6 mi.

Closest Point of Approach.—Pacific walruses were observed twice as close to source vessels during 2006 Chukchi Sea seismic periods compared to non–seismic periods (n = 12 for both seismic and non–seismic source vessel sightings). MMOs on support vessels also reported a smaller mean CPA value for Pacific walruses during seismic compared to non–seismic periods, but the sample size during the seismic period was limited (n = 5). Overall, Pacific walruses approached support vessels nearly twice as close as source vessels in 2006 (Table 3.21).

TABLE 3.21. Comparison of Pacific walrus CPA distances by seismic period from useable sightings aboard source and support vessels during 2006 and 2007 Chukchi Sea vessel operations.

Effort Category	Mean CPA[a] (m)	s.d.	Range (m)	*n*
2006				
Source Vessels Seismic	556	198	304-1115	*12*
Source Vessels Non-seismic	1097	563	396-2165	*12*
Source Vessels Mean	***826***	***497***	***304-2165***	***24***
Support Vessels Seismic	60	52	*20-150*	*5*
Support Vessels Non-seismic	520	547	10-2500	*98*
Support Vessels Mean	***498***	***543***	***10-2500***	***103***
2007				
Source Vessels Seismic	875	598	82-2324	*17*
Source Vessels Non-seismic	905	621	71-3037	*190*
Source Vessels Mean	***903***	***618***	***71-3037***	***207***
Support Vessels Seismic	280	305	*5-1631*	*37*
Support Vessels Non-seismic	291	443	1-3423	*90*
Support Vessels Mean	***287***	***406***	***1-3423***	***127***

[a] CPA = *Closest Point of Approach* . For source vessels this value is the marine mammal's closest point of approach to the airgun array, for support vessels this value is the marine mammal's closest point of approach to the MMO/vessel.

There was almost no difference in Pacific walrus mean CPA values when comparing seismic with non–seismic periods for source vessels in 2007 (Table 3.21). The walrus CPAs reported from support vessels were also similar during seismic and non–seismic periods in 2007. However, the CPA from source vessels was over three times that recorded from support vessels during both seismic and non–seismic periods in 2007 (Table 3.21).

Distance from Ice Detection Rates.— Pacific walrus detection rate from support vessels was higher in areas with ice and areas near ice compared to areas more than 20 km (12.4 mi) from ice during 2006 Chukchi Sea vessel operations (Fig. 3.48). This pattern did not hold true for source vessels in 2006, however useable source vessel effort in areas with or near ice was low and precluded a thorough analysis of Pacific walrus detection rates with respect to distance from ice. Source vessel MMOs detected more Pacific walruses in areas with at least some ice as opposed to ice–free areas in 2006 (Fig. 3.48).

Pacific walrus detection rates were higher from support vessels the closer those vessels were to ice in the Chukchi Sea in 2007 (Fig. 3.48). An opposite trend was observed from source vessels in 2007 and higher Pacific walrus detection rates were recorded further from ice. This result, however, was likely related to low source vessel effort near ice and the 24 Aug sighing event that occurred more than 20 km (12.4 mi) from ice.

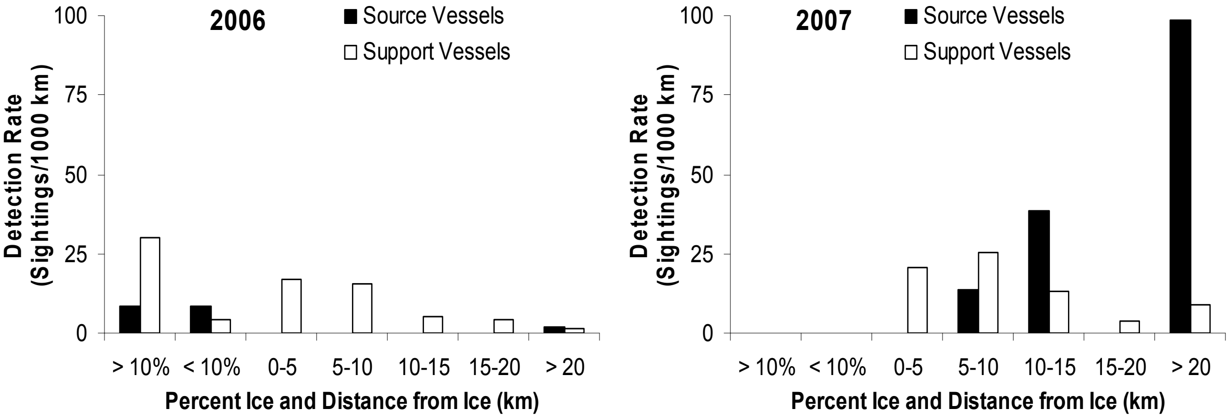

FIGURE 3.48. Detection rates from useable Pacific walrus sightings by percent ice and distance from ice recorded during 2006 and 2007 Chukchi Sea vessel operations.

Distance from Shore Detection Rates.—Pacific walrus detection rates from support vessels in nearshore areas in 2006 Chukchi Sea vessel operations were lower than in offshore areas (Fig. 3.49). Pacific walrus detection rates in offshore areas of 2006 still were relatively low, though the rate from support vessels was nearly twice that from source vessels.

The absence of useable nearshore effort for the source vessel during 2007 Chukchi Sea surveys precluded a comparison of Pacific walrus detection rates in nearshore areas between vessel groups. The source vessel was greater than 25 km (15.5 mi) from shore on 24 Aug when MMOs recorded 143 useable Pacific walrus sightings, and this resulted in an offshore detection rate which was more than 11 times greater than the offshore detection rate from support vessels (Fig 3.49). If the *Gilavar's* 24 Aug sightings are omitted from offshore detection rate calculations the value drops by 67% but still is nearly four times greater than the offshore detection rate reported from support vessels. Pacific walrus detection rates from support vessels in offshore and nearshore areas were similar in 2007 and were higher than detection rates form source vessels in 2006 (Fig 3.49).

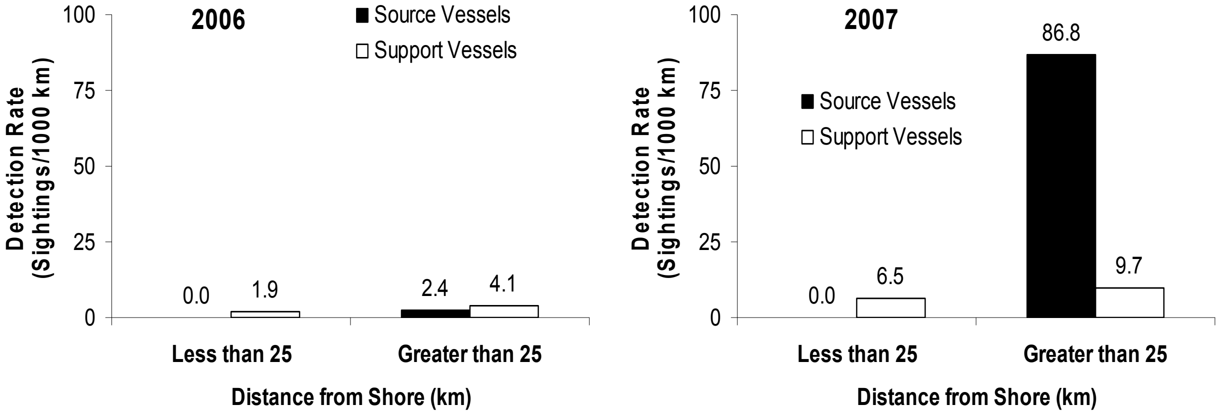

FIGURE 3.49. Detection rates from useable Pacific walrus sightings by distance from shore recorded during 2006 and 2007 Chukchi Sea vessel operations.

Behavior

Movement.—Most walruses observed during seismic periods from the source vessels in 2006 were moving neutrally, followed by swimming toward and swimming away (Fig. 3.50). However, the sample size from source vessels during seismic periods was relatively low compared to other combinations of vessel, year, and seismic state. In 2007, most walrus movement recorded from source vessels during seismic periods was either unknown or neutral, although swimming away and swimming toward were also recorded. No movement was the primary movement recorded from support vessels during seismic periods in 2006, with the remaining initial movements records distributed equally across unknown, neutral, and swim toward. In 2007, over 50% of the initial walrus movement recorded from support vessels during seismic periods was neutral, followed by swim away.

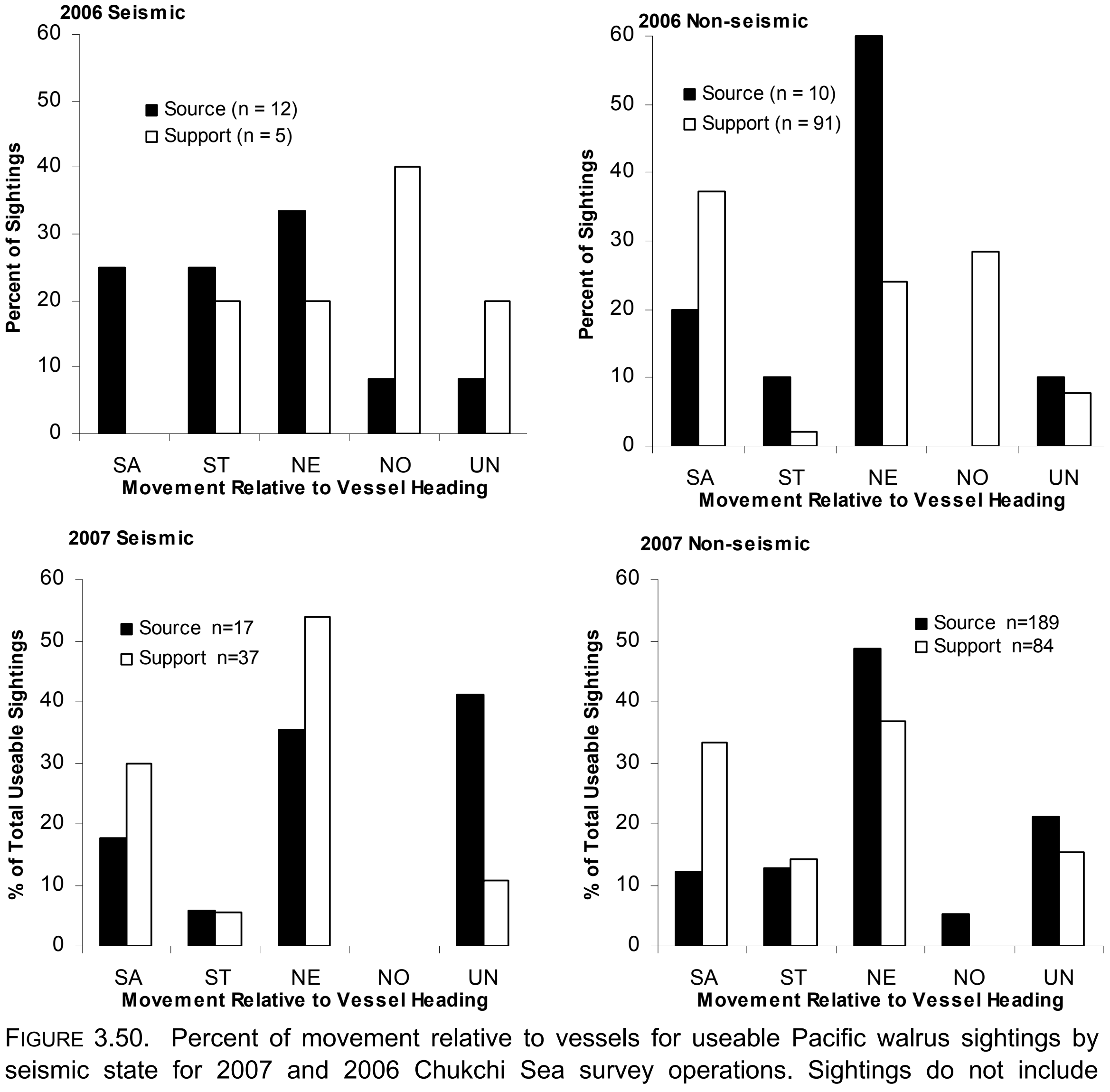

FIGURE 3.50. Percent of movement relative to vessels for useable Pacific walrus sightings by seismic state for 2007 and 2006 Chukchi Sea survey operations. Sightings do not include walruses hauled out.. SA = Swim Away, ST = Swim Toward, NE = Neutral, NO = None, UN = Unknown.

Initial Behavior.—The breakdown of initial behaviors displayed by Pacific walruses during seismic versus non–seismic periods was very similar in 2006. The most notable difference in Pacific walrus behavior between seismic states was reported from source vessels where walruses were observed looking at the vessel more often during seismic compared to non–seismic periods (Fig. 3.51).

Pacific walruses appeared to spend more time active at the surface during non–seismic compared to seismic periods for both vessel groups during 2007 Chukchi Sea operations. MMOs from both source and support vessels also reported walruses resting, looking, and diving more frequently during non–seismic periods compared to seismic periods in 2007. Swimming was the most commonly recorded Pacific walrus behavior across 2006 and 2007 (Fig. 3.51).

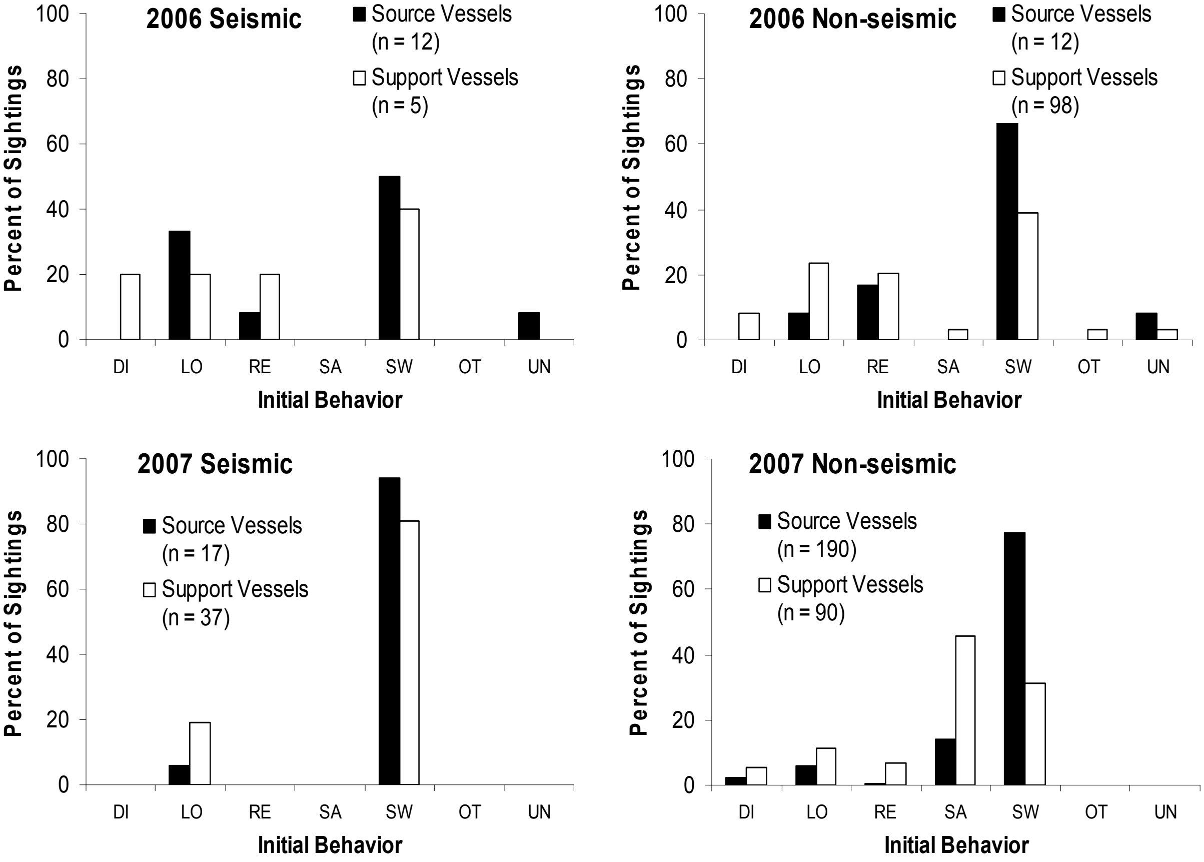

FIGURE 3.51. Percent of individuals performing initial behavior for useable Pacific walrus sightings by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations. DI = Dive, LO = Look, RE = Rest, SA = Surface Active, SW = Swim, OT = Other, UN = Unknown.

Reaction Behavior.—The majority of Pacific walruses did not show a reaction to vessels in 2006 or 2007. In 2007, source vessel MMOs rarely recorded a walrus reacting to the vessel during non–seismic periods whereas MMOs on support vessels reported a combination of changing direction, increasing speed, looking, and splashing for roughly 40% of non–seismic walrus sightings. Support vessel MMOs reported walrus reactions for less than 20% of sightings during seismic periods whereas source vessel MMOs recorded walrus reactions (looking) for over 40% of seismic period walrus sightings (Fig. 3.52). In 2006 the predominant reaction behavior (other than no reaction) recorded by MMOs on source and support vessels during seismic and non–seismic periods was changing direction and looking (Fig. 3.52).

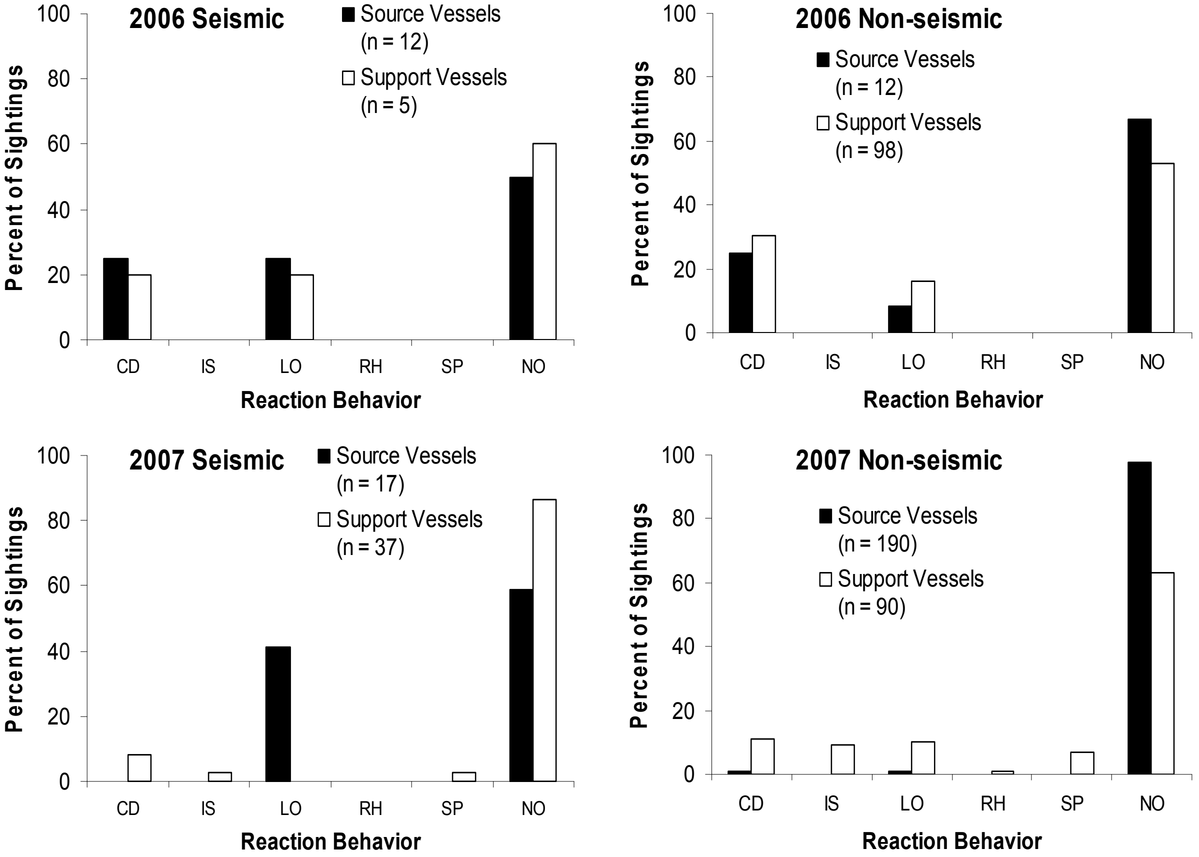

FIGURE 3.52. Percent of individuals performing reaction behavior for useable Pacific walrus sightings by seismic state recorded during 2006 and 2007 Chukchi Sea vessel operations. CD = Change Direction, IS = Increase Speed, LO = Look, RH = Rush (from ice or land into water), SP = Splash, NO = No Reaction.

Pacific Walrus Detection Rates Relative to Received Sound Levels

If walrus were avoiding seismic activity, detection rates should decrease as received sound levels increase. Based on observations by MMOs from support vessels during seismic survey activities in 2007, Pacific walrus detection rates were generally higher at locations where received sound levels were relatively high (Table 3.22). However, most sound level categories above 120 dB (rms) had insufficient useable effort (<500 km) to produce conclusive results and these data should be viewed with caution (Table 3.22). This analysis does not include source vessel data, and therefore, the large numbers of Pacific walruses recorded from the *Gilavar* on 24 Aug were not considered.

TABLE 3.22. Number of detections, amount of useable effort (km), and detection rates (detections/1000 km) for Pacific walrus observed from support vessels within 10 dB (rms) received sound level categories during seismic periods in the Chukchi Sea during 2006 and 2007.

	2006			2007		
Received Sound Exposure Level (dB re1 µPa rms)	Number of Sightings	Useable Effort (km)	Detection Rate (sightings / 1000 km)	Number of Sightings	Useable Effort (km)	Detection Rate (sightings / 1000 km)
< 120	54	8139.5	6.6	8	2219.9	3.6
120 - 129	6	1565.1	3.8	5	552.7	9.0
130 - 139	11	2372.7	4.6	1	411.2	2.4
140 - 149	4	2311.0	1.7	7	439.7	15.9
150 - 159	4	2107.7	1.9	17	511.1	33.3
160 - 169	9	5162.2	1.7	2	160.5	12.5
170 - 179	3	1681.1	1.8	7	316.4	22.1
180 - 189	1	46.9	21.3	10	268.9	37.2

Estimated Number of Pacific Walruses Potentially Ensonified

Estimates from direct observations.—The numbers of Pacific walruses directly observed within the areas ensonified to specific dB (rms) levels provide minimum estimates of the number of individuals exposed at these received levels. For this analysis, data were not filtered using the usability criteria outlined in the *Methods* section. Table 3.23 presents the number of walruses observed within distances where received levels were ≥ 160, 170, and 190 dB (rms) in the Chukchi Sea during 2007. It is possible that some walruses present within these areas were not detected by observers, and therefore these numbers are likely underestimates of the number of individuals ensonified at the various levels.

TABLE 3.23. Total number of walruses observed within the areas ensonified to levels ≥160, 170, and 190 dB re 1 µPa (rms) in 2007.

	Individuals	
Received Sound Exposure Level (dB re1 µPa rms)	**2006**	**2007**
≥ 160	81	108
≥ 170	40	70
≥ 190	18	24

Estimates Extrapolated from Density.—Walrus density estimates for 2007 in Table 3.24 account for sightability bias to correct for the number of animals likely present in a given area that were not detected by observers. Density estimates were only calculated when useable effort exceeded 500 km. The walrus sightings (n = 143) recorded from the *Gilavar* during a non–seismic period on 24 Aug contributed significantly to the summer, source vessel, non–seismic density estimate. Marine mammals are patchily distributed, and density estimates will vary greatly if a dense aggregation such as this is encountered. For illustrative purposes, a second density estimate that excluded the 24 Aug data was ~65% lower than the original density estimate. When data from source and support vessels were pooled, the difference between estimates that included versus excluded the 24 Aug data decreased to ~32% of the original estimate due to the greater amount of effort and relatively few walrus sightings contributed by support vessels.

Density estimates from support vessels during seismic periods in the fall were much greater than from source vessels suggesting possible localized walrus avoidance of the source vessel during seismic activities. However, the lack of sufficient effort during non–seismic periods from source vessels limited the ability to make meaningful comparisons.

TABLE 3.24 Walrus density estimates based on data collected during seismic and non–seismic periods in the Chukchi Sea during 2007. Dashes (–) indicate categories in which sufficient useable effort (<500 km or 310 mi) was unavailable to calculate a density estimate.

	No. individuals / 1000km^2		
	Summer	Fall	
Vessel Type	Non-seismic	Seismic	Non-seismic
Source Vessels			
Including 24 Aug 2007	592.3	-	-
Excluding 24 Aug 2007	205.8	13.2	-
Support Vessels			
Including 24 Aug 2007	-	-	-
Excluding 24 Aug 2007	106.9	82.2	31.4
All Vessels			
Including 24 Aug 2007	174.9	-	-
Excluding 24 Aug 2007	119.5	61.7	29.6

- indicates less than 500 km of useable effort

The estimated numbers of walruses exposed to various received sound levels using data collected during seismic and non–seismic periods in 2007 are presented in Table 3.25. These values are from SOI's 2007 operations 90–day report (Funk et al. 2008) and the 2006 operation JMP report (Funk et al. 2007). The amount of useable effort from vessels directly involved with seismic operations in the Chukchi Sea in 2007 was insufficient to calculate reliable density estimates. As an alternative, all daylight effort and sightings from these vessels were used to calculate the density estimates used in estimating exposures (for details see Funk et al. 2008). Density estimates for 2007 were based on a summer period that extended from Jul through 10 Sep to include all of the seismic activity that occurred in the Chukchi Sea before the *Gilavar* moved into the Beaufort Sea (Funk et al. 2008). In 2006, Pacific walruses were included as part of the overall pinniped density estimates (Table 3.18). Non–seismic estimates represent the number of animals that would have been exposed had they not shown localized avoidance behavior in response to the airguns or the vessels themselves.

TABLE 3.25. Estimated numbers of individual Pacific walruses exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual within the Chukchi Sea during both the summer and fall survey periods in 2007. Estimates are based on "corrected" densities of Pacific walruses calculated from daylight MMO watch effort, and numbers of exposures based on both seismic and non–seismic densities are shown.

	Non-seismic Densities		**Seismic Densities**	
Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures per Individual**	**Individuals**	**Exposures per Individual**
Summer*				
≥160	525	18.5	133	18.5
≥170	338	13.4	85	13.4
≥180	253	8.9	64	8.9
≥190	119	3.9	30	3.9
Fall				
≥160	0	13.7	2	13.7
≥170	0	9.7	1	9.7
≥180	0	7.0	1	7.0
≥190	0	3.4	0	3.4
Total**				
≥160	525	26.0	134	26.0
≥170	338	17.7	87	17.7
≥180	253	11.5	65	11.5
≥190	119	3.6	30	3.6

* Estimated number of Pacific walruses exposed to 160, 170, 180, and 190 dB using daylight non-seismic densities decrease from 525, 338, 253, and 119, respectively, to 320, 206, 154, and 72, respectively, when *Gilavar* 24 Aug sightings (*n* = 148) are excluded from density calculations.

** Totals may not add up to sum of summer and fall values due to rounding

In 2006, pinniped seasons were defined differently. The "early season" was defined as the period before 28 Aug, the "mid–season" was from 28 Aug through 8 Oct, and the "late season" was from 9 Oct onward, whereas in 2007, the more general summer (Jul–Aug) and fall (Sep–Nov) season definitions were applied for the same reasons discussed in the cetacean section above. In 2006, the data were partitioned by nearshore and offshore, whereas in 2007, there were insufficient data to compare seal density in nearshore and offshore areas. Because of these differences it is difficult to compare 2006 and 2007 data directly.

The non–seismic density estimates in Table 3.25 include the data collected on August 24, 2007. Excluding this data results in an estimate that is approximately 40% lower. The number of walruses actually exposed to sound at a given level was probably much lower than the estimates in Table 3.25.

Polar Bears

Sightings

Total Sightings.—There were no polar sightings during 2007 Chukchi Sea vessel operations. In 2006, MMOs aboard support vessels documented five useable polar bear sightings of five individuals and no useable polar bear sightings were recorded from source vessels. Four of the 2006 Chukchi Sea polar bear sightings were of animals on ice and one bear was observed in the water. The incompatibility of ice and seismic operations is likely to minimize the amount of time vessels, particularly source vessels, operate in areas of favorable polar bear habitat.

Detection Rates by Season.—The five 2006 Chukchi Sea polar bear sightings from support vessels all occurred during the fall season. Fall detection rates for polar bears from support vessels were low, with an average of one bear detected every 2326 km (1445 mi) of useable MMO effort.

Detection Rates by Seismic State.—All five of the useable polar bear sightings from 2006 Chukchi Sea vessel operations were recorded during non–seismic periods. The resulting support vessel non–seismic polar bear detection rate was low with only one bear detected per 4348 km (2702 mi) of useable non–seismic MMO effort.

Distribution

Closest Point of Approach.—A meaningful discussion of polar bear CPA is not possible due to the low sample size (n=5). The five polar bears observed during non–seismic periods ranged in distance from 100 m (109 yd) to 1000 m (1094 yd) from support vessels with an average CPA of 571 m (624 yd; standard deviation = 361 m [395 yd]).

Distance from Ice Detection Rates.—Because the data used to determine ice concentration were gathered from satellite imagery and summarized weekly, only three of the five polar bear sightings from 2006 were associated with ice even though all five sightings occurred with ice present as recorded by observers on the vessels. There were insufficient data to analyze polar bear sighting rates with respect to ice, but it is generally assumed that most polar bears are associated with ice.

Distance from Shore Detection Rates.—All five of the 2006 polar bear sightings were recorded from support vessels greater than 25 km (15.5 mi) offshore, though the resulting offshore detection rate was still low at one sighting per 4762 km (2959 mi) of useable offshore effort.

Behavior

Initial Behavior.—All five of the 2006 polar bear sightings were made from a support vessel during non–seismic periods. Three of the five 2006 polar bear sightings were initially observed walking on ice, one was looking from ice, and one was observed swimming.

Reaction Behavior.—Three of the five 2006 polar bears showed no detectable reaction to the vessel. One of the two bears that showed a reaction looked at the vessel and the other changed the direction in which it was walking.

Polar Bear Detection Rates Relative to Received Sound Levels

No polar bears were recorded from support vessels near seismic survey activity in the Chukchi Sea during 2007. It is possible that some polar bears were present within ensonified areas and were not detected by observers, however given that seismic activities occurred away from ice, no polar bears were likely ensonified at levels ≥ 160 dB (rms).

Estimated Number of Polar Bears Potentially Ensonified

Estimates from Direct Observations.—No polar bears were observed within ensonified areas in the Chukchi Sea during 2007. It is possible that some polar bears not detected by observers were present within areas where seismic sounds were detectable, however given that seismic activities occurred away from ice, it is unlikely that any polar bears were ensonified at levels ≥ 160 dB (rms).

Estimates Extrapolated from Density.—Because no polar bears were observed in ensonified areas, it was not possible to calculate estimates extrapolated from density. It is unlikely that any polar bears were exposed to seismic noise exceeding 160 dB (rms) in the Chukchi Sea during 2007.

DISCUSSION

Prior to 2006, the most recent vessel–based observations of marine mammals in the offshore Chukchi Sea were recorded during exploratory drilling activities in 1991 (Brueggeman et al. 1992). The data summarized by Brueggeman et al. (1992) were collected from an icebreaker operating near drilling activities, with 43% of the observation effort occurring while the vessel was stationary. Data summarized in this report were collected from periods when vessels were underway, making direct comparison of sightings data difficult. Between 1991 and 2006, observers aboard a small number of other vessels have recorded marine mammal sightings during brief transits of the Chukchi Sea during the open–water season (Haley and Ireland 2005, Haley 2006). The limited amount of time spent in the Chukchi Sea during these transits also make comparison to the current results problematic. Comparisons between and within the two years of data described in this report are perhaps the most useful.

Environmental conditions in the Chukchi Sea, particularly ice cover, differed greatly between the two years with almost four times as much ice present in 2006 compared to 2007. The reduced ice cover in 2007 may have contributed to the generally higher sea conditions and poorer visibility recorded by observes in 2007. There were also large differences in observation effort and seismic survey activity between the two years. In 2006, three different vessels collected seismic data during the course of the season while in 2007 only one vessel collected seismic data. The lower amount of effort resulted in small sample sizes in 2007 which sometimes limited our ability to make meaningful comparisons between years.

Some seasonal differences in cetacean sightings between the two years were identified. For example, compared to 2006, cetacean sighting rates in 2007 were higher in Jul–Aug and lower in Sep–Nov. The lower fall cetacean sighting rates in 2007 compared to 2006 may have resulted from a later or somewhat prolonged bowhead whale migration through the Beaufort Sea in 2007. Bowhead whales observed from aerial surveys in the Beaufort Sea were commonly noted as feeding well into Sep (Chapter 7) suggesting the presence of greater food resources may have contributed to a later appearance of bowhead whales in the Chukchi Sea in 2007. Higher cetacean detection rates in Jul–Aug of 2007 may have been caused, at least in part, by the reduced amount of ice present compared to the same period in 2006.

In both years, cetacean detection rates recorded from both source and support vessels were higher during non–seismic periods than during seismic periods. This suggests that whales may be avoiding the seismic survey activity at distances greater than can be detected by observers on the vessels and is consistent with results from previous seismic surveys in the Arctic (Malme 1986, 1988; Miller et al. 1999, 2005; Richardson et al. 1999). In 2007 the detection rate of cetaceans from the source vessel during non–seismic periods was much greater than that from support vessels. However, the source vessel had a higher observation platform than most of the support vessels, allowing observers to detect cetaceans at greater distances.

Using ESW as a measure of the distance to which observers could reliably detect marine mammals, observers aboard the taller vessels from which seismic surveys were conducted were able to detect cetaceans at greater distances from the vessel than observers aboard the shorter support vessels. The expected trend of increasing ESW with increasing number of observers was true for cetacean sightings aboard the taller vessels, but not aboard the shorter vessels. The ESW for seal sightings showed little increase with addition of a second observer, but increased substantially when a third observer was present. Poorer sea conditions reduced the ESW for seal detections in almost all cases, but the trend was not as consistent for cetacean sightings for which there were fewer data available.

Seal detection rates were lower in 2007 compared to 2006. In 2006, the data showed an expected relationship of greater seal detection rates in areas closer to pack ice suggesting the lower overall seal detection rate in 2007 may be due, in part, to decreased ice cover in areas where vessels were operating. In 2007 seal detection rates were generally greater from support vessels than source vessels, and the difference was greater during seismic than during non–seismic periods. The same trend of increased detection rates from support vessels during seismic periods was found in 2006, and may suggest that seals are reacting to the active airguns by moving away from the source vessel. However, a clear trend indicating avoidance was not found when detection rates within 10 dB sound level increments were examined. A reaction behavior was recorded for ~30% of seal sightings from source vessels during seismic periods and for ~20% of sightings during non–seismic periods suggesting somewhat greater levels of disturbance during seismic periods.

Overall, Pacific walrus sighting rates were higher in 2007 than in 2006 which was coincident with the rapid retreat of ice in 2007. Pacific walrus sightings (n = 143) recorded from the source vessel during a non–seismic period on 24 Aug contributed 72% of the non–seismic marine mammal sightings in 2007. This sighting event suggests that Pacific walruses tend to be patchily distributed and large aggregations of walruses swimming in open water may be encountered during years when ice retreats northward beyond the shallow waters of the Chukchi Sea. Similar to trends in seal sightings in 2006, walrus detection rates in 2006 tended to be higher in areas near ice than areas farther from ice. However in 2007 walrus sighting rates were generally higher in areas farther from ice. This was likely a result of the absence of ice in the Chukchi Sea during 2007. Walruses used land–based haulouts along the Alaskan and Russian Chukchi Sea coast when ice became unavailable (Chapter 4). During aerial surveys conducted along the Chukchi Sea coast in 2007, much higher walrus detection rates were recorded during coastline surveys (339.8 walrus/1000 km) than during surveys extending ~40 km (~25 mi) offshore (21.4 walrus/1000 km; Chapter 4), and the 2007 coastline detection rate was 96% higher than in 2006. From vessels, walruses were observed in greater numbers offshore than within 25 km (15.5 mi) of shore in 2007, although effort in nearshore areas was limited. Sighting rates from support vessels far exceeded those from source vessels during seismic periods, however, the opposite was true during non–seismic periods, suggesting localized avoidance of seismic airguns by walruses. For the majority of walrus sightings, no reaction to the vessel was noted during both seismic and non–seismic periods.

Based on data collected aboard vessels in 2006 and 2007, no physical injury to marine mammals was observed, and estimates of the number of marine mammals exposed to seismic sounds above behavioral (≥160 dB rms) and safety (≥180 or ≥190 dB rms) thresholds were low relative to population sizes. In the Arctic, pinnipeds are often associated with ice and it is likely that lower numbers of pinnipeds will be exposed to industrial activities in years when ice cover is low, or when activities occur far from ice. However, this may not be true in years when Pacific walruses are forced to use terrestrial haul outs. Changing environmental conditions may mean additional cetacean species will become more common in the Chukchi Sea as evidenced by observations of small numbers of humpback whales in both the Chukchi and Beaufort seas in 2007.

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4. CHUKCHI SEA NEARSHORE AERIAL SURVEYS[1]

INTRODUCTION

Prior to 2006, aerial surveys of marine mammals during the open–water season in the Chukchi Sea had not been conducted since the 1980s and early 1990s. Distribution and abundance of marine mammal species may have changed since those surveys (George et al. 2004; Rugh 2004; Cooper et al. 2006) due to differences in habitats used by some species related to global warming and changing ice conditions (Tynan and DeMaster 1997; Johannessen et al. 1999; Ferguson et al. 2001; Stirling and Parkinson 2006; Treacy et al. 2006). In 2006, aerial surveys of marine mammals over the nearshore waters of the Chukchi Sea were conducted as part of an industry–funded Joint Monitoring Program (JMP) by Shell Offshore Inc. (SOI), ConocoPhillips Alaska Inc. (CPAI), and GX Technology (GXT). The objective of these surveys was to gather up–to–date information on marine mammal distribution and abundance in the eastern Chukchi Sea (Funk et al 2007). These aerial surveys were continued in 2007 by SOI (with support from CPAI) to supplement the 2006 data and identify yearly fluctuations in distribution and abundance estimates. The surveys focused on beluga, bowhead, and gray whales, although other marine mammals were recorded when observed. Sightings of pinnipeds were collected during the surveys and pinniped distribution and sighting–rate data are presented, but these data should be interpreted with caution as flight altitude and speed limited the ability of observers to collect consistent and reliable data on those species.

The eastern Chukchi Sea stock of beluga whales was estimated to contain ~3,710 individuals in 1991 (based on 1989–91 aerial surveys), and the population size is considered stable (Angliss and Outlaw 2007). However, more recent estimates are not available to confirm this stable status. During Jun–Jul the Chukchi stock of beluga whales is typically found in nearshore waters and in lagoons along the Alaskan Chukchi Sea coast. The coastal villages, most notably Pt. Lay, conduct subsistence hunts for beluga whales during this period. By Aug, most Chukchi Sea beluga whales have moved into the northern Chukchi Sea, the Arctic Ocean, or into the western Beaufort Sea, where they spend the rest of the summer (Suydam et al. 2001; NMFS 2006). These whales return to the southern Chukchi Sea during their fall migration in Oct (NMFS 2006). The much larger Beaufort Sea stock of beluga whales (39,258; Angliss and Outlaw 2007) also migrates through the eastern Chukchi Sea during their spring (Apr– early Jun) and fall (Oct) migrations.

The Bering/Chukchi/Beaufort Sea (BCB) stock of bowhead whales was estimated to contain about 10,545 animals as of 2001, with lower and upper 95% confidence bounds of 8200 and 13,500 animals (Zeh and Punt 2005). Between 1978 and 2001 this bowhead population was estimated to have increased at a rate of 3.4% per year (95% confidence interval 1.7 to 5.0%) with an annual subsistence harvest (landed animals) averaging 38.4 whales during 2000 through 2004 (Angliss and Outlaw 2007). If a 3.4% annual rate of increase continued after 2001, the 2007 population size would be ~12,900 bowhead whales.

In spring (Apr to mid–Jun) bowhead whales migrate north from the Bering Sea through the open leads in the Chukchi Sea along the west coast of Alaska. They continue across the Alaskan Beaufort Sea and into the Canadian Beaufort Sea and Amundsen Gulf, arriving there in Jun and Jul (Moore and Reeves 1993). Although most bowheads appear to migrate to the Canadian Beaufort Sea for the summer, there is evidence that small numbers of bowheads may remain in the northeastern Chukchi Sea (Moore 1992). In fall, most bowhead whales migrate west through the central Alaskan Beaufort Sea during Sep and Oct,

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but after reaching Barrow, their migration route back to the Bering Sea remains largely unknown (Moore et al. 1995). Some whales are thought to migrate southwest from Barrow (Moore 1993) while others migrate westward from Barrow, before heading south along the Chukotka coast. This migration route has been observed for satellite–tagged bowheads in fall (Mate et al. 2000; Quakenbush et al. 2007). Moore et al. (1995) observed bowhead whales along the Chukotka Coast during opportunistic mammal/seabird surveys in the Chukchi Sea in autumn 1992 and 1993, and a satellite–tagged bowhead spent at least a month, probably feeding (Schell et al. 1989; Thomson et al. 2002; Lee et al. 2005), along the Chukotka coast during autumn 2006 before migrating into the Bering Sea wintering area (Quakenbush et al. 2007).

The Eastern North Pacific stock of gray whales was estimated to contain 29,758 animals in 1997–1998, but estimates were lower for 2000–01 (19,448) and 2001–02 (18,178; Rugh et al. 2005). Rugh et al. (2005) also estimated the carrying capacity (*K*) to be 26,290 (CV=0.059) animals for this stock of gray whales. During the 1980s, some of this stock migrated to the Chukchi Sea to feed, arriving in mid–Jun (Braham 1984; Moore et al. 1986; Moore 2000), but in recent years, several tens of gray whales have been seen near Barrow by early Jun (W. Koski survey data from 2003 and 2004). Some gray whales continue east into the Beaufort Sea (Reeves et al. 2002; Angliss and Outlaw 2007; Appendix D, Figure D.4A), but most remain in the Chukchi Sea until Sep–Oct, when they migrate south to wintering areas in northern Mexico and southern California (Moore et al. 1986). Recent evidence from acoustical data suggests that some gray whales may overwinter in the Barrow area (Stafford et al. 2007).

Alaskan Natives from several villages along the east coast of the Chukchi Sea hunt marine mammals during the summer, and there is concern that offshore oil and gas development activities may negatively impact their ability to harvest marine mammals. Of particular concern for summer activities are potential impacts on the early summer beluga harvest at Point Lay and on fall bowhead harvests at Point Hope, Wainwright and Barrow. Native hunters at Point Hope and Wainwright have traditionally hunted bowheads in the spring, when the whales pass through leads relatively close to shore, but these villagers have not traditionally hunted bowheads during the fall. The spring bowhead harvests at Point Hope and Wainwright occur while sea ice is still present in high concentrations, and industry seismic vessels are not able to operate. Members of the coastal communities also hunt seals and walruses for subsistence purposes.

Objectives

An aerial survey program was conducted as part of the JMP during seismic activities in the Chukchi Sea in the summer and fall of 2006, and by SOI during seismic activities in the Chukchi Sea in the summer and fall of 2007. The objective of the aerial surveys was to collect data on the current distribution and relative abundance of marine mammals in coastal areas of the eastern Chukchi Sea during the open–water season.

METHODS

Aerial surveys for marine mammals in the eastern Chukchi Sea were conducted twice per week from 9 Jul through 12 Nov 2006 and 10 Jul through 4 Nov 2007 using a standard survey route, weather permitting. A total of 25 surveys in 2006 and 30 surveys in 2007 were attempted.

Survey Area

The aerial survey area extended from Barrow to Point Hope, Alaska and from the mainland coast to ~37 km (23 mi) offshore (Fig. 4.1). Within this survey area, two series of systematic transects were flown. The "sawtooth" surveys provided broad–scale survey coverage of the entire survey area. The "coastline" surveys provided additional opportunities to detect marine mammals in nearshore areas, including lagoons, where most subsistence hunting occurs.

Sawtooth Survey

The "sawtooth" survey grid flown in 2006–07 nominally consisted of 22 transect lines (total length ~1015 km or 631 mi) in a sawtooth pattern. The survey pattern was developed in consultation with scientists from the National Marine Fisheries Service (NMFS) and the North Slope Borough (NSB). Survey transects were determined by placing transect start/end points every 55 km (34 mi) along the offshore boundary of the survey area and at points along the shore midway between the offshore points. The transect line start/end points were shifted along both the coast and the offshore boundary for each survey based upon a randomized starting point. Overall, distance did not vary substantially among surveys. This design permitted near completion of the survey in one to two days, depending on the aircraft used, and provided representative coverage of the nearshore area from the shore to ~37 km (23 mi) offshore. The Aero Commander aircraft used prior to 26 Jul 2006 allowed the survey to be completed in one day, weather permitting. After 26 Jul 2006, surveys were flown in a Twin Otter aircraft, which was slower and had less fuel capacity than the Aero Commander, and required two days to complete a survey.

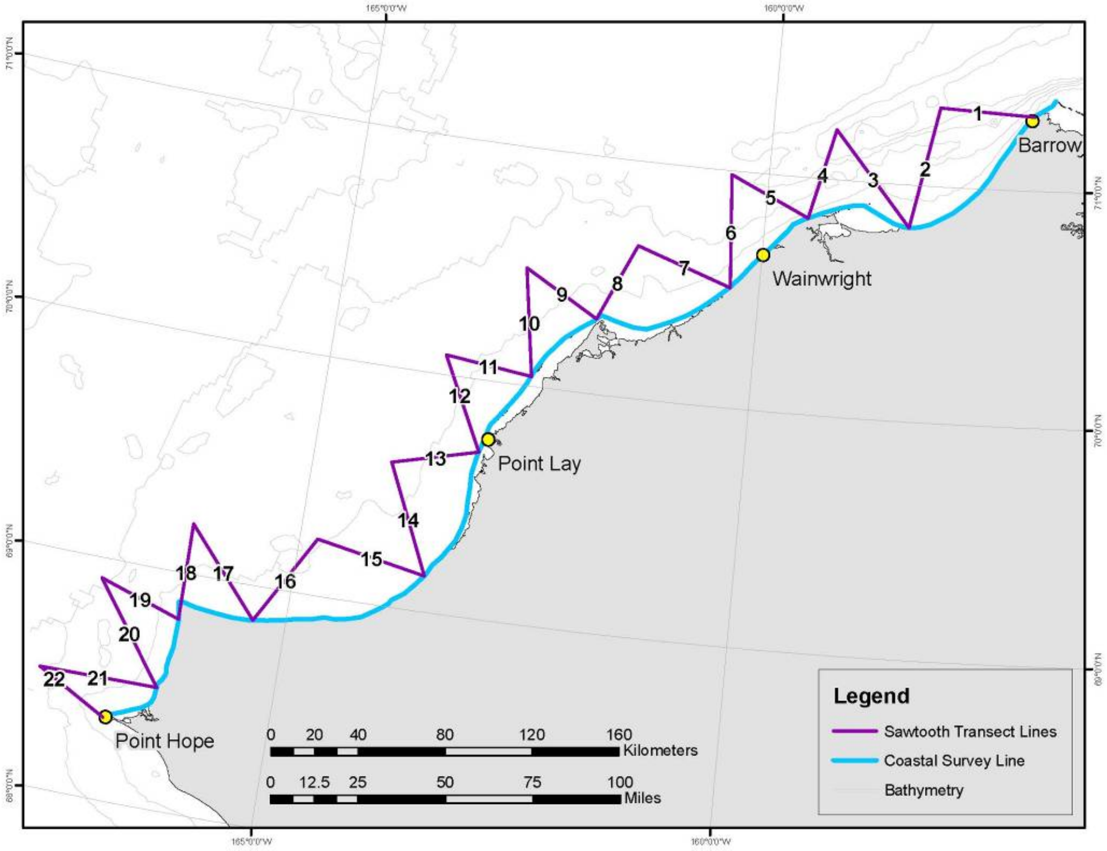

FIGURE 4.1. Aerial survey transect locations and general survey patterns for the eastern Chukchi Sea, summer 2006–07.

Coastline Survey

The shorter "coastline" survey (total length ~560 km or 348 mi) was flown either on the return trip to Barrow after completion of the sawtooth survey, or en route to the southwestern end of the survey area on days when the survey began near Point Hope. The coastline survey was designed to determine the distribution of beluga and gray whales in coastal areas and lagoons, but was not designed to calculate abundance estimates. Another objective of the coastal surveys was to document spotted seal and walrus haulouts and numbers of animals using those sites.

Survey Procedures

From 9 to 25 Jul 2006, aerial surveys were flown in a twin–engine, high–wing Aero Commander N222ME aircraft specially modified for survey work. The plane was operated by Commander Northwest of Anchorage, Alaska. Special features included upgraded engines, STOL modifications to allow safer flight at low speeds, long–range fuel tanks, multiple GPS navigation systems, bubble windows at all observer positions, 110 V AC power for survey equipment, and a camera port for taking photos. Two pilots were present for takeoffs, landings, and ferry flights. For the remainder of the 2006 field season, from 22 Aug through 12 Nov, the aerial surveys were flown in a Twin Otter EA320 operated by ERA Aviation, Inc. of Anchorage, Alaska. This twin–engine, high–wing aircraft was also specially modified for survey work similar to the Aero Commander, although without a camera port and with a shorter flight duration. Twin Otter aircraft operated by either Bald Mountain, Alaska or Ken Borek of Calgary, Alberta were used to conduct surveys during the 2007 field season from 10 Jul through 4 Nov. These twin–engine high–wing aircrafts were also specially modified for survey work. The special features included wing–tip fuel tanks, multiple GPS navigation systems, bubble windows at all observer positions, and 110 V AC power for survey equipment. Two pilots were present for takeoffs, landings, and ferry flights.

When conditions permitted, both the sawtooth and the coastline surveys were flown. Fuel capacity of the Twin Otter aircraft precluded completion of the entire sawtooth portion of the survey without refueling. In general, the coastline was flown first from Barrow to transect 9, and then the sawtooth portion was flown from transects 9 to 22. The aircraft was refueled in Kotzebue to fly the coastline survey from Point Hope to transect 8. Then the sawtooth portion from transects 8 to 1 were flown. If the survey could not be completed in one day, the survey was finished the next day. Transects 1 to 4 were frequently flown on the second day; however, on several occasions the sequence was modified because of weather restrictions in part of the survey area.

Surveys were conducted at altitudes of 305 to 457 m (1000–1500 ft) above sea level (ASL) and a groundspeed of 222 km/h (138 m/h). An altitude of 457 m ASL (1500 ft) was maintained in the Ledyard Bay spectacled eider critical habitat area during 1 Jul through 28 Aug, as required by USFWS regulation. This critical habitat area extended from Icy Cape to Cape Lisburne. The preferred altitude outside the critical habitat area was 305 m ASL (1000 ft), but some surveys were conducted at higher altitudes during periods when there was concern about potential aircraft disturbance to whaling activities at Barrow, Wainwright, Point Lay and Point Hope. "No–fly" zones around coastal villages or other hunting areas established during communications with village representatives were in place during hunting seasons. For example, during the summer beluga whaling season (Jul 2006), transects 19 through 22 were not surveyed to avoid potential aircraft disturbance to whaling by Point Hope (as per their request). Also, during the 2006 fall whaling season in Barrow (25 Sep through 2 Oct), transects 1 and 2 of the sawtooth survey were flown at 457 m (1500 ft), and in 2007 transects 1 and 2 were not surveyed from 5 through 10 Oct to avoid the potential aircraft disturbance to whaling. These procedures were implemented to provide as much coverage of the survey area as possible while minimizing the potential for aircraft disturbance to whales in the whaling area and maximizing the probability that the aircraft would be at high altitude (457 m), where bowheads generally do not react to aircraft overflights (Patenaude et al. 2002).

Data Recording Procedures

A laptop computer using Garmin NRoute software automatically recorded time and aircraft position (latitude and longitude) at 2–s intervals throughout the flights. The electronics system consisted of a portable computer, GPS unit (Garmin GPSmap 76CSx), and NRoute data–logging software. In addition to the automated flight–track recording, locations were recorded through keystrokes initiated by the computer operator at various times, including when animals were sighted by one of the observers, transect starts and ends, ends of 2–minute time periods, marine mammal sightings, and other observations or comments.

The two primary observers recorded the time, sightability (subjectively classified as excellent, good, moderately impaired, seriously impaired, or impossible), sea conditions (Beaufort wind force), ice cover (in 10ths) and sun glare (none, up to 10% glare, 10–30% glare, >30% and <70% glare, and >70% glare) onto digital recorders at the end of each 2–minute (~7.4 km or 4.6 mi) period. The time and position of the aircraft were automatically logged by the NRoute software when the time period data were entered.

For each whale sighting, the observer notified the computer operator of the species and number seen and then dictated details of the sighting into a portable digital recorder, including the species, number, ice conditions, size/age/sex class when determinable, activity, heading, swimming speed category, sighting cue, inclinometer angle (taken when the animal's location was 90° to the side of the aircraft track), and altitude. In conjunction with aircraft altitude, inclinometer readings allowed calculation of lateral distances of whales from the transect line. Non–transect sightings were identified as being recorded along “Connect” segments (between transect lines) and “Search” segments (seen while circling). For pinnipeds and polar bears, only the species, number, and ice conditions were routinely dictated. In addition to recording sighting data on the digital recorder, time and position of the sighting were recorded in the NRoute software. The whale sighting information entered into the software in real time was cross–checked against the recorded dictation after each survey to correct any data entry errors.

Analyses of Aerial Survey Data

Mapping.—This report includes maps showing the sighting locations of cetaceans and pinnipeds during the surveys. These maps show the sawtooth and coastline surveys encompassing the 156°42'–167°39' W (approx.) and 68°21’–71°22' N (approx.) region. The sightings were divided into monthly periods for cetaceans and for pinnipeds. Each sighting symbol on these maps represents a sighting of one or more individuals. Sightings along formal transects (regardless of distance from trackline) are shown as filled (useable data, defined below) or ‘dotted’ (unusable data) symbols. Incidental sightings, including sightings during “Connect” legs between transects and during non–systematic “Search” legs, are shown as open symbols and were not used in the analyses.

Usability Criteria.—Effort and sightings were defined as “useable” when made under the following conditions: Beaufort wind force 4 or less for whales and Beaufort wind force 2 or less for pinnipeds, sightability moderately impaired or better, and glare ≤30%. Unusable data refers to sightings and effort collected under poor conditions, i.e., Beaufort wind force 5 or more for whales, and Beaufort wind force 3 or more for pinnipeds, or sightability seriously impaired or impossible, or glare >30%. These sightings, and the associated survey effort under poor conditions, were excluded from analyses of sightings per unit effort and density calculations. Additionally, sightings of animals hauled out on land were considered unusable. The large aggregations of walrus observed at terrestrial haulouts in 2007 are excluded from most analyses below, but are presented separately later in the chapter.

Whales and Pinnipeds per Unit Effort (Relative Abundance).—The maps illustrate much of the distributional information. However, the maps do not account for survey effort which varied considerably within the survey area. To account for this variability, we computed sightings and individuals per unit effort and densities for both the Coastline and the Sawtooth surveys. For the coastline surveys, we considered an effort of >200 km (124 mi) as adequate coverage from which sightings rates could be calculated. For the sawtooth surveys, we considered an effort of >500 km (311 mi) as adequate coverage to calculate sightings rates.

We used NRoute, supplemented by MapBASIC computer code, to determine and summarize numbers of kilometers of transect coverage within the survey area. These analyses excluded survey effort and sightings during non–systematic "Connect" and "Search" segments, as well as unusable data segments. Sightings or individuals per unit effort were determined by dividing the number of sightings (or individuals) seen during the survey by the number of kilometers of useable effort.

Estimated Number of Whales Present.—Line transect methodology (Buckland et al. 2001) was used to estimate densities and numbers of whales present in the survey area. We used the DISTANCE program to estimate numbers of whales present for each survey when there was sufficient survey effort to meet assumptions of this methodology (Thomas et al. 2006, version 5.0, release 2). When beluga whale sightings included clusters of animals, a cluster analysis was performed in the DISTANCE program to estimate the number of animals. When clusters exceeded 16 individuals, correction factors were not applied to these sightings, as their detectability and availability were assumed to be 1.00.

The lateral distance factor, $f(0)$, accounts for the reduced probability of detecting an animal at the surface of the water as its distance from the trackline increases. During estimation of $f(0)$, we identified inner truncation distances for each combination of aircraft type, altitude and species (as in Thomas et al. 2002). For a Twin Otter aircraft, the inner truncation distances varied from 80–110 m from the centerline at 305 m (1000 ft) ASL and 250–300 m at 457 m (1500 ft) ASL. For the Aero Commander aircraft, the inner truncation distance was 450 m at 305 m (1000 ft) and 457 m (1500 ft). The outer truncation distances were calculated for each whale species using data during good sighting conditions (sea conditions between 0–4 and ice–cover between 0–5%; Thomas et al. 2002). For beluga, gray, and bowhead whales the outer truncation distances were calculated and varied between 1000–2360 m depending on species and altitude.

The availability bias factor, $g_a(0)$, takes into account the effects of surfacing and dive behavior on the probability that an animal on or near the trackline will be at the surface while the surveyors are close enough to have a chance of detecting the animal. It was calculated for each whale species as in Thomas et al. (2002) using data from earlier studies. For beluga whales, the $g_a(0)=0.58$ was calculated from data in Martin and Smith (1992). For bowhead whales, the $g_a(0)=0.144$ for animals sighted in deeper waters on sawtooth transects was taken from Thomas et al. (2002), and $g_a(0)=0.357$ for bowheads sighted in shallower waters on the coastline transects was calculated from behavioral data on animals <4 km from shore. The $g_a(0)=0.32$ for migrating gray whales was taken from Forney and Barlow (1998), and $g_a(0)=0.292$ for feeding gray whales was calculated from data in Würsig et al. (1986).

The number of cetaceans present was estimated for each survey. For the coastline surveys, we calculated the number of cetaceans within 4 km of the coast (an area of 2240 km^2 or 865 mi^2), but these estimates should be interpreted with caution as the coastline survey was designed to examine whale use of the immediate area of the coast rather than determine whale density or abundance. For the sawtooth surveys, we calculated the number of whales within an area of 19,022 km^2 (7609 mi^2), which encompassed the entire survey area. A "bootstrap" resampling method was used to calculate the weighted mean and 95% confidence intervals to estimate abundance for the three common cetacean species in the survey area during each month.

Distances from Shore and Seasonal Occurrence.—We examined the distribution of whales within the nearshore survey area by dividing the survey area into a series of strips, each 5 km wide, oriented roughly parallel to the coast. This allowed a more detailed examination of the distribution and abundance of the whales in the survey area relative to the shoreline. We combined survey data from the two regions (coastline and sawtooth) to get a better overall view of the whale distribution. These analyses were restricted to useable data to allow meaningful calculations of sightings and individuals per unit effort during different parts of the season. Thus, "zero" sightings or individuals in a particular strip signified that there were no sightings during conditions suitable for systematic aerial surveys, not necessarily that there were no sightings in those strips. Given the irregularities in the coastline, and the presence of islands along some parts of the coast, a "0 km from shore" reference point was established. Waters inshore of the "0 km" line are shallow nearshore waters, in some cases inside lagoons. The sighting rates at different distances from shore are compared for 2006 and 2007. The significance of the differences in distributions was determined using Kolmogorov–Smirnov tests, hereafter called K–S tests. The distance–from–shore data were originally plotted, analyzed, and statistically tested by 5–km distance–from–shore bands. However, dividing the small samples into so many small bands resulted in highly variable sighting rates in adjacent distance–from–shore bands. In this report we have shown the distance–from–shore data plotted by 10–km bands. This results in smoother curves that are easier to interpret, and are probably more reliable because the effort is higher. The first distance–from–shore band (also referred to as –5 km band) represented the area inshore of the "0 km" line out to 5 km offshore, resulting in this band being less than 10 km wide at times. K–S tests were not conducted using the 10–km band data because the sample sizes were too small.

Similarly, we examined the relative abundance of whales in the survey area by monthly periods from Jul to Nov to determine seasonal changes in abundance. The K–S test was again used to look at any differences in temporal distribution. For this test, we divided the seasons into 15–day intervals to get an adequate sample size.

Behavior.—Marine mammal habitat use and movement in the survey area were assessed by the behavior, swimming speeds, and headings of the whales during all surveys, including useable and unusable data, and off–transect sightings. The program Oriana was used to calculate the vector mean heading, angular standard deviations, and the Rayleigh test of uniformity.

RESULTS

Coastline Surveys

Ice Cover.—In 2007, the survey area was predominately ice–free from Jul to mid–Oct, with only isolated small ice pans in Jul. By 17 Oct ice pans and slush had started to form along the coast from Barrow to Cape Lisburne, and by 23 Oct large portions of the coastal areas were covered in ice. In contrast, during the 2006 aerial surveys pack ice was always present within some portion of the survey area from Jul to mid–Sep. A standard area was defined in which to compare ice coverage between 2006 and 2007 as discussed in the Introduction of Chapter 3. Ice concentration in the standardized area was 3.6 times greater in 2006 than 2007.

Cetaceans

Survey Effort.—Aerial surveys were flown from 9 Jul through 4 Nov 2007 and a total of 10,548 km (6554 mi) of coastline transects was flown with 82% during useable conditions. Effort level was similar in 2006 (10,887 km; 6765 mi) with 79% occurring during useable conditions (Figure 4.2A). Approximately 60 and 69% of the useable effort in 2006 and 2007, respectively, was flown in Beaufort <3 (Figure 4.2B). Appendix Table B.1–2 summarizes the aerial survey effort and whale sightings for each coastline survey that had useable data in 2006–07. Appendix B contains daily aerial survey maps showing the coastline transects surveyed each day and the whale sightings in 2007 (Fig. B.1 – B.15).

Total or partial aerial survey coverage of the coastline was obtained on 28 surveys (during 45 days) in 2007 and 25 surveys (37 days) in 2006 (Appendix Table B1–2). Adequate coverage of the survey area was obtained on 20 surveys in 2007 and 22 surveys in 2006. Substantially reduced coverage of the survey area was obtained during eight surveys in 2007 and three surveys in 2006. This reduced coverage was due to low clouds, precipitation, high sea conditions, or some combination of those factors.

Sightings.—There was a total of 94 cetacean sightings of an estimated 118 individuals during coastline surveys within the Chukchi Sea in 2007 (Table 4.1). During the 2006 field season, less than half as many cetacean sightings were recorded although the total number of individual cetaceans was greater in 2006 than 2007 (Table 4.1). The most frequently recorded cetacean species in 2007 was gray whale, although a higher number of individual beluga whales was sighted.

Useable sightings of beluga whales were made on 18 and 24% of coastline surveys in 2007 and 2006, respectively. In 2007, 55% of beluga sightings were of individual whales. This was similar to the 40% recorded in 2006. Mean group size of the remaining sightings was higher in 2007 (4.3 and 7.8 in 2006 and 2007, respectively), although on one occasion in 2006 a group of 295 beluga whales was seen which was not factored into the mean group size.

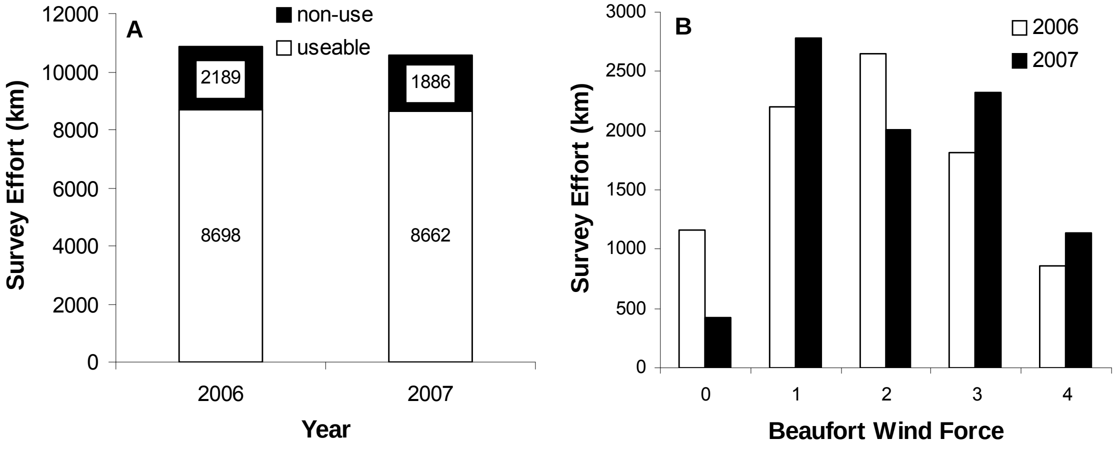

FIGURE 4.2. Cetacean aerial survey effort for the coastline surveys in the eastern Chukchi Sea, 2006–07. (A) Total survey effort (useable and unusable) in 2006–07, (B) Useable survey effort in each Beaufort wind force category in 2006–07.

Useable sightings of bowhead whales were made on 21 and 16% of coastline surveys in 2007 and 2006, respectively. Bowheads were always seen as single animals on the coastline surveys in both years.

Gray whale was the most consistently observed whale species during coastline surveys, and useable sightings of gray whales were made on 39 and 40% of coastline surveys in 2007 and 2006, respectively. In 2007, 84% of gray whale sightings were of individual whales. This was similar to the 93% recorded in 2006. Mean group size of the remaining sightings was also similar between years (2.0 and 3.0 in 2006 and 2007, respectively).

Abundance.—The numbers of whales present during each month were estimated for the coastal area consisting of a 4–km band adjacent to the coastline. The estimates were based on all surveys, each of which was flown on one or two consecutive days during the 2007 field season (Table 4.2). The estimates were calculated at the request of some stakeholders, and should be viewed with caution as the coastline surveys were not designed to calculate density and abundance estimates.

During the 2007 field season, an average of 13 to 36 beluga whales were estimated to have been present along the coastline during each survey, with the highest numbers seen in Aug (Table 4.2). Peak numbers of bowhead whales were present in Oct–Nov, which was consistent with their expected migration patterns. Gray whales were most common during Jul and Aug, which also was consistent with their expected migration patterns. Overall, numbers of whales along the coastline were much lower during the 2006 field season except for belugas during July (Table 4.3).

TABLE 4.1. Useable cetacean sightings (number of individuals) recorded during coastline aerial surveys in the Chukchi Sea for 2006, 2007, and 2006–07 combined.

Species	2006	2007	2006-07
Beluga Whale	15 (335)	29 (118)	44 (453)
Bowhead Whale	7 (7)	23 (23)	30 (30)
Gray Whale	15 (16)	32 (42)	47 (58)
Harbour Porpoise	0	1 (1)	1 (1)
Unknown Whale	3 (2)	9 (10)	12 (12)
Total Cetaceans	40 (360)	94 (194)	134 (554)

TABLE 4.2. Estimated numbers of whales near the coastline in the eastern Chukchi Sea survey area by month in 2007, including allowance for $f(0)$, and $g_a(0)$ correction factors.

Species/Month	No. of surveys	Effort (km)	Sightings[a]	Individuals[a]	Density (No./1000km^2)[b]	Est. No. Whales[b]	CV[b]	95% C.I.[b]	
Beluga									
July	5	1759	4	32	10.0	13	0.94	0	41
August	7	2777	12	40	18.7	36	0.74	2	101
September	6	1273	2	3	6.3	14	1.17	0	57
Oct-Nov	10	2852	8	38	10.6	13	1.00	0	45
Bowhead									
July	5	1759	0	0	0.0	0	-	-	-
August	7	2777	1	1	0.6	1	1.00	0	4
September	6	1273	0	0	0.0	0	-	-	-
Oct-Nov	10	2852	21	21	21.9	50	0.46	11	100
Gray									
July	5	1759	7	8	7.9	18	0.28	9	28
August	7	2777	23	32	18.6	41	0.41	13	78
September	6	1273	1	1	1.9	4	0.99	0	15
Oct-Nov	10	2852	0	0	0.0	0	-	-	-

[a] Excludes sightings between trackline and inner truncation distance (80–300 m, depending on aircraft altitude and type); also excludes sightings beyond outer truncation distance (1000–2360 m, depending on aircraft altitude, sea conditions, ice cover and species).

[b] Calculated using a Bootstrap resampling method of the abundance estimates calculated by the DISTANCE program for each survey, including use of $f(0)$ and $g_a(0)$ correction factors to correct for whales missed because they were at the surface but not recorded by observers or because they were submerged when the aircraft passed over them.

TABLE 4.3. Estimated numbers of whales near the coastline in the eastern Chukchi Sea survey area by month in 2006, including allowance for $f(0)$, and $g_a(0)$ correction factors.

Species/Month	No. of surveys	Effort (km)	Sightings[a]	Individuals[a]	Density (No./1000km^2)[b]	Est. No. Whales[b]	CV[b]	95% C.I.[b]	
Beluga									
July	6	2211	8	320	81.2	88	0.90	0	277
August	3	674	0	0	0.0	0	-	-	-
September	6	2027	0	0	0.0	0	-	-	-
Oct-Nov	10	2707	2	4	3.9	9	0.58	0	20
Bowhead									
July	6	2211	3	3	6.9	16	1.06	0	58
August	3	674	0	0	0.0	0	-	-	-
September	6	2027	1	1	4.3	10	0.98	0	32
Oct-Nov	10	2707	2	2	5.8	13	0.64	0	31
Gray									
July	6	2211	3	3	3.1	7	0.59	0	15
August	3	674	3	3	5.9	13	0.62	0	43
September	6	2027	2	2	1.2	3	0.90	0	8
Oct-Nov	10	2707	4	5	3.3	8	0.44	2	15

[a] Excludes sightings between trackline and inner truncation distance (100–450 m, depending on aircraft altitude and type); also excludes sightings beyond outer truncation distance (1000–2000 m, depending on aircraft altitude, sea conditions, ice cover and species).

[b] Calculated using a Bootstrap resampling method of the abundance estimates calculated by the DISTANCE program for each survey, including use of $f(0)$ and $g_a(0)$ correction factors to correct for whales missed because they were at the surface but not recorded by observers or because they were submerged when the survey aircraft passed over them.

Pinnipeds

Survey Effort.—Of the 10,548 km (6554 mi) of coastline transect flown in 2007, only 49% was useable for pinniped sightings. This was similar to the 55% of effort in 2006 that was useable for pinniped sightings (Figure 4.3). Appendix Table B.3–4 summarizes the aerial survey effort and pinniped sightings for each coastal survey that had useable data in 2006 and 2007. Appendix B contains daily aerial survey maps showing the coastline transects surveyed each day and the pinniped sightings in 2007 (Fig. B.1 – B.15).

Adequate coverage of the survey area was obtained on 14 surveys in both 2007 and 2006. Substantially reduced coverage of the survey area was obtained during 12 surveys in 2007 and 11 surveys in 2006 due to low clouds, precipitation, high sea conditions, or some combination of those factors.

Sightings.—There was a total of 313 pinniped sightings of an estimated 593 individual pinnipeds observed during coastline surveys within the Chukchi Sea in 2007 (Table 4.4). During the 2006 field season, less than a third as many pinnipeds were observed (Table 4.4). The most commonly recorded pinniped species in 2007 was Pacific walrus, whereas in 2006, Pacific walrus was the least observed pinniped species on the coastline surveys. Because these surveys were designed to collect and analyze data from sightings over water, the large aggregations of walrus observed at terrestrial haulouts in 2007 were considered unusable and are not included in the data presented in this section. However, an additional section presenting those data is present towards the end of this chapter.

Useable sightings of walrus were made on 50% (13 of 26) of coastline surveys in 2007, compared to only 16% (4 of 25) of the surveys in 2006. In 2007, 55% of walrus sightings were of individual animals. This is very similar to the 50% recorded in 2006. Mean group size of the remaining sightings was also similar between years (3.8 and 3.5 in 2006 and 2007, respectively).

Useable sightings of bearded seals were recorded on 15 and 25% of coastline surveys in 2007 and 2006, respectively. In 2007, 73% of bearded seals sightings were of individual seals. This was similar to the 87% recorded in 2006. Group sizes of the remaining sightings ranged between 2 to 5 individuals.

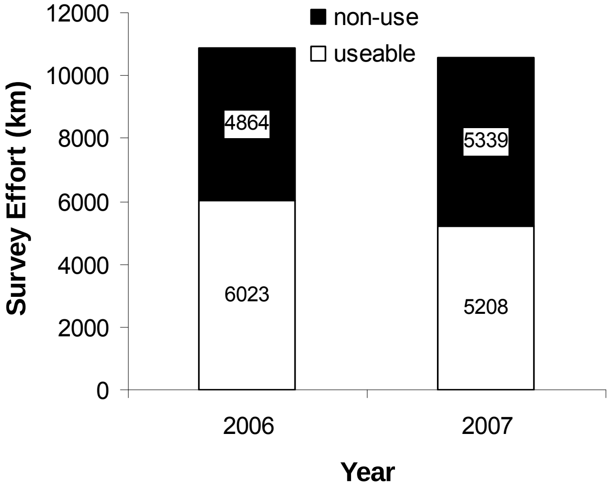

FIGURE 4.3. Total pinniped survey effort (useable and unusable) for coastline surveys of the Chukchi Sea, 2006–07.

TABLE 4.4. Useable pinniped sightings (number of individuals) recorded during coastline aerial surveys in the Chukchi Sea for 2006, 2007, and 2006–07 combined.

Species	2006	2007	2006-07
Pacific Walrus	8 (19)	177 (376)	185 (395)
Bearded Seal	15 (18)	15 (22)	30 (40)
Ringed and Spotted Seals	74 (160)	115 (189)	189 (349)
Unknown Pinniped	0	6 (6)	6 (6)
Total Pinnipeds	97 (197)	313 (593)	410 (790)

Because ringed and spotted seals are difficult to distinguish during aerial surveys at 1000 ft we have combined ringed, spotted and unknown seals into a single group called "Ringed and Spotted Seals" for the purpose of comparing the two field seasons. Useable sightings of ringed and spotted seals were recorded on 65 and 56% of coastline surveys in 2007 and 2006, respectively. Ringed and spotted seals were seen singly on 81% of the sightings in 2007 and 2006. Mean group size of the remaining sightings was higher in 2006 (7.1 and 4.4 in 2006 and 2007, respectively).

Sawtooth Surveys

Ice Cover.—Ice–cover conditions are described above in the section on coastline surveys.

Cetaceans

Survey Effort.—From 9 Jul through 4 Nov 2007 a total of 18,667 km (11,599 mi) of sawtooth transects was flown with 73% during useable conditions. Effort level was similar in 2006 (19,232 km or 11,950 mi), with 73% occurring during useable conditions (Figure 4.4A). Approximately 70 and 65% of the useable effort in 2007 and 2006, respectively, was flown in Beaufort <3 (Figure 4.4B). Appendix Table B.5–6 summarizes the aerial survey effort and whale sightings for each sawtooth survey that had useable data in 2006–07. Appendix B contains daily aerial survey maps showing the sawtooth transects surveyed each day and the whale sightings in 2007 (Fig. B.1 – B.15).

Total or partial aerial survey coverage of the sawtooth surveys was obtained on 29 surveys during 51 days in 2007, and 25 surveys during 42 days in 2006. Adequate coverage of the survey area was obtained on 16 surveys in 2007 and 17 surveys in 2006. Substantially reduced coverage of the survey area was obtained during thirteen surveys in 2007, and eight surveys in 2006 due to low clouds, precipitation, high sea conditions, or some combination of those factors.

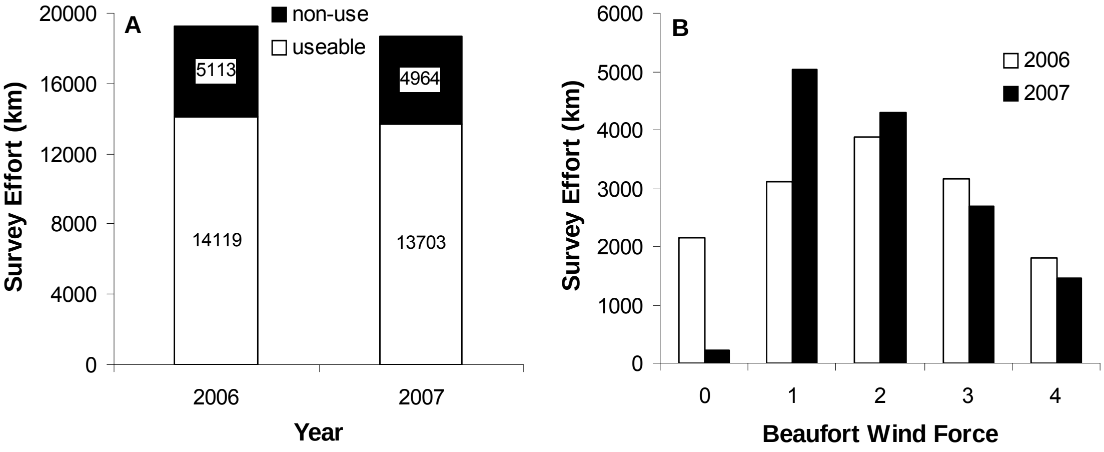

FIGURE 4.4. Cetacean aerial survey effort for the sawtooth surveys in the Chukchi Sea, 2006–07. (A) Total survey effort (useable and unusable) for 2006–07, (B) Useable survey effort in each Beaufort wind force category in 2006–07.

Sightings.— There were 189 cetacean sightings of an estimated 640 individuals observed during sawtooth surveys within the Chukchi Sea in 2007 (Table 4.5). During the 2006 field season, less than a third as many cetacean sightings were recorded (Table 4.5). The most commonly recorded cetacean species in 2007 was gray whale, although beluga whales had higher numbers of individuals.

Useable sightings of beluga whales were made on 34 and 32% of sawtooth surveys in 2007 and 2006, respectively. In 2007, 52% of beluga whale sightings were of individual whales. This was similar to the 65% recorded in 2006. Mean group size was higher in 2007 (19.0 and 3.1 in 2007 and 2006, respectively).

Useable sightings of bowhead whales were made on 21 and 28% of sawtooth surveys in 2007 and 2006, respectively. In 2007, 92% of bowhead sightings were of individual whales. This is similar to the 82% recorded in 2006. Mean group size of the remaining sightings was similar between years (3.0 and 2.0 in 2006 and 2007, respectively).

Gray whale was the most consistently observed whale species for 2006 and 2007 combined. Useable sightings of gray whales were made on 48 and 44% of sawtooth surveys in 2007 and 2006, respectively. In 2007, 85% of gray whale sightings were of individual whales. This was higher than the 61% recorded in 2006. Mean group sizes of the remaining sightings were similar between years (2.3 and 2.4 in 2006 and 2007, respectively).

TABLE 4.5. Useable cetacean sightings (number of individuals) recorded during sawtooth aerial surveys in the Chukchi Sea for 2006, 2007, and 2006–07 combined.

Species	2006	2007	2006-07
Beluga Whale	20 (35)	48 (461)	68 (496)
Bowhead Whale	17 (23)	13 (14)	30 (37)
Gray Whale	18 (27)	117 (143)	135 (170)
Unknown Whale	1 (1)	11 (22)	12 (23)
Total Cetaceans	56 (86)	189 (640)	245 (726)

Abundance.—The mean numbers of whales present in the Chukchi Sea survey area during each month were estimated for the 19,022 km^2 (7344 mi^2) of nearshore waters covered by the sawtooth surveys. The estimates were based on all surveys combined for each month, each of which was flown on one day or two consecutive days during the 2007 field season (Table 4.6).

Beluga whales were commonly encountered in the sawtooth survey area during aerial surveys in Jul–Aug and smaller numbers remained there into Oct–Nov (Tables 4.6–7). The highest estimated numbers of beluga whales were recorded in Jul in both 2006 and 2007, although the number was higher in 2007 than 2006 (1645 and 183 in 2007 and 2006, respectively). There were considerably fewer beluga whales in the sawtooth survey area in 2006 than 2007 (Tables 4.6–7).

Bowhead whales were not encountered in the sawtooth survey area during aerial surveys in Jul through Sep 2007, but bowheads were recorded in Jul and Sep in 2006 (Tables 4.6–7). The estimated numbers of bowhead whales in the sawtooth survey area in Oct–Nov were similar between years (594 and 634 in 2006 and 2007, respectively) (Tables 4.6–7).

TABLE 4.6. Estimated numbers of whales in the sawtooth survey area of the eastern Chukchi Sea by month in 2007, including allowance for *f*(0), and $g_a(0)$ correction factors.

Species/Month	No. of surveys	Effort (km)	Sightings[a]	Individuals[a]	Density (No./1000km^2)[b]	Est. No. Whales[b]	CV[b]	95% C.I.[b]	
Beluga									
July	5	2515	21	329	127.3	1645	0.60	0	3792
August	8	5248	19	122	18.9	185	0.52	46	391
September	7	3569	2	4	2.4	45	0.68	0	113
Oct-Nov	9	2371	3	3	2.4	47	0.86	0	127
Bowhead									
July	5	2515	0	0	0	0	-	-	-
August	8	5248	0	0	0	0	-	-	-
September	7	3569	0	0	0	0	-	-	-
Oct-Nov	9	2371	11	11	33.2	634	0.23	329	900
Gray									
July	5	2515	22	25	15.8	301	0.30	103	460
August	8	5248	71	85	23.1	438	0.28	219	683
September	7	3569	10	12	7.2	137	0.50	30	294
Oct-Nov	9	2371	0	0	0	0	-	-	-

[a] Excludes sightings between trackline and inner truncation distance (80–300 m, depending on aircraft altitude and type); also excludes sightings beyond outer truncation distance (1000–2360 m, depending on aircraft altitude, sea conditions, ice cover and species).

[b] Calculated using a Bootstrap resampling method of the abundance estimates calculated by the DISTANCE program for each survey, including use of *f*(0) and $g_a(0)$ correction factors to correct for whales missed because they were at the surface but not recorded by observers or because they were submerged when the aircraft flew over them.

TABLE 4.7. Estimated numbers of whales in the sawtooth survey area of the eastern Chukchi Sea survey area, based on Jul–Nov 2006 surveys, including allowance for $f(0)$, and $g_a(0)$ correction factors.

Species/Month	No. of surveys	Effort (km)	Sightings[a]	Individuals[a]	Density (No./1000km^2)[b]	Est. No. Whales[b]	CV[b]	95% C.I.[b]	
Beluga									
July	6	3185	3	10	9.6	183	0.63	0	436
August	3	1103	1	1	1.5	29	0.82	0	87
September	6	2898	5	5	3.9	75	0.65	0	177
Oct-Nov	10	5292	6	10	4.6	88	0.65	0	213
Bowhead									
July	6	3185	1	1	1.3	24	0.95	0	79
August	3	1103	0	0	0.0	0	-	-	-
September	6	2898	2	2	2.8	53	0.91	0	162
Oct-Nov	10	5292	12	18	30.7	594	0.76	0	1648
Gray									
July	6	3185	8	13	6.8	130	0.33	48	222
August	3	1103	1	3	4.9	95	0.86	0	313
September	6	2898	3	4	2.0	38	0.55	0	78
Oct-Nov	10	5292	1	1	0.2	4	0.94	0	14

[a] Excludes sightings between trackline and inner truncation distance (100–450 m, depending on aircraft altitude and type); also excludes sightings beyond outer truncation distance (1000–2000 m, depending on aircraft altitude, sea conditions, ice cover and species).

[b] Calculated using a Bootstrap resampling method of the abundance estimates calculated by the DISTANCE program for each survey, including use of $f(0)$ and $g_a(0)$ correction factors to correct for whales missed because they were at the surface but not recorded by observers or because they were submerged when the aircraft flew over them.

Gray whales were commonly encountered in the sawtooth survey area in Jul and Aug and smaller numbers were observed into Sep and Oct (Tables 4.6–7). The estimated numbers of gray whales in the sawtooth survey area were highest in Jul 2006 and in Aug 2007 (130 and 438 in 2006 and 2007, respectively; Tables 4.6 and 4.7). There were considerably fewer gray whales in the sawtooth survey area in 2006 than 2007.

Pinnipeds

Survey Effort.—Of the 18,666 km (11,573 mi) of sawtooth transects flown in 2007, only 51% were useable for pinniped sightings. Similarly, of the 19,232 km (11,924 mi) of sawtooth transects flown in 2006, only 48% were useable (Figure 4.5). Appendix Table B.7–8 summarizes the aerial survey effort and pinniped sightings for each nearshore survey that had useable data in 2006–07. Appendix B contains daily aerial survey maps showing the sawtooth transects surveyed each day and the pinniped sightings in 2007 (Fig. B.1 – B.15).

Adequate coverage of the survey area was obtained on five surveys in both 2007 and 2006. Substantially reduced coverage of the survey area was obtained during 22 surveys in 2007 and 20 surveys in 2006.

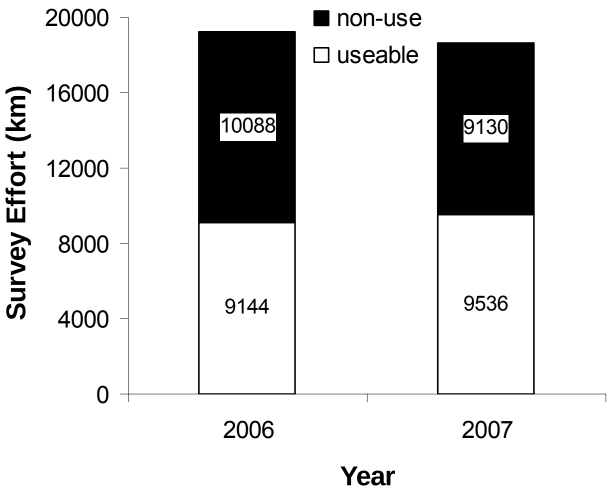

FIGURE 4.5. Pinniped aerial survey effort for the sawtooth surveys of the Chukchi Sea nearshore areas, 2006 and 2007. Total survey effort (useable and unusable) for 2006 and 2007.

Sightings.—There were 506 pinniped sightings of an estimated 1102 individuals during sawtooth surveys within the Chukchi Sea in 2007 (Table 4.8). During the 2006 field season, a similar number of sightings was recorded (Table 4.8). The most commonly recorded pinniped classification in both 2006 and 2007 was ringed and spotted seals, although more Pacific walrus individuals were recorded each year.

Useable sightings of walrus were made on 59 and 48% of sawtooth surveys in 2007 and 2006, respectively. In 2007, 56% of walrus sightings were of individual walrus. This was similar to the 48% recorded in 2006. Mean group size of the remaining sightings was higher in 2006 than in 2007 (29.9 and 5.2 in 2006 and 2007, respectively). The mean group sizes were larger in 2006 because walrus were hauled out on ice pans where data were considered useable, whereas in 2007, no ice was present and walrus were often hauled out on beaches, and these sightings were considered nonuseable for these analyses.

Useable sightings of bearded seals were made on 26% of sawtooth surveys in 2007. They were more commonly seen during the 2006 surveys (64% of surveys). Bearded seals were seen singly on 88% of the sightings in 2007 and 2006, and in groups ranging from 2 to 3 individuals on the remaining sightings.

As stated previously, ringed, spotted, and unknown–seal sightings were grouped into a single category called "ringed and spotted seals" for the purpose of comparing the two field seasons. Useable sightings of ringed and spotted seals were made on 74 and 84% of nearshore surveys in 2007 and 2006, respectively. In 2007, 82% of ringed and spotted seal sightings were of individual seals. This was similar to the 81% recorded in 2006. Mean group size of the remaining sightings was also similar between years (5.5 and 5.3 in 2006 and 2007, respectively).

TABLE 4.8. Useable pinniped sightings (number of individuals) recorded during sawtooth aerial surveys in the Chukchi Sea in 2006, 2007 and 2006–07 combined.

Species	2006	2007	2006-07
Pacific Walrus	110 (1742)	204 (581)	314 (2323)
Bearded Seal	77 (86)	25 (29)	102 (115)
Ringed and Spotted Seals	340 (621)	274 (489)	614 (1110)
Unknown Pinniped	0	3 (3)	3 (3)
Total Cetaceans	527 (2449)	506 (1102)	1033 (3551)

Coastline and Sawtooth Surveys

Cetaceans

Distribution.—Beluga whales were sighted throughout the survey area during the 2007 field season, with most sightings occurring in the northern half of the survey area (Figure 4.6). A similar distribution was observed during the 2006 field season.

Bowhead whales were found in the northern portion of the survey area, with all sightings occurring north of 70° N latitude (Figure 4.7). A similar distribution was observed during the 2006 field season.

Gray whales were sighted throughout the survey area during the 2007 field season, with most sightings occurring in the northern half of the study area (Figure 4.8). During the 2006 field season, gray whales had a slightly different distribution. They were more concentrated in the central portion of the survey area, with most sightings occurring between Cape Lisburne (68°50' N latitude) and Icy Cape (70°20' N latitude), and closer to shore.

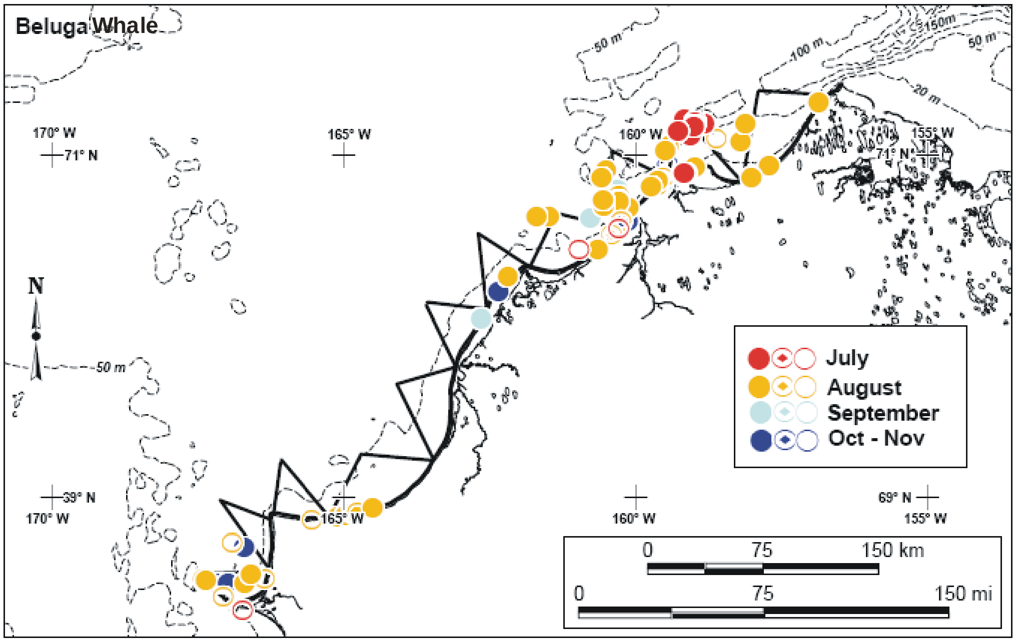

FIGURE 4.6. Locations of beluga whale sightings during aerial surveys in the eastern Chukchi Sea during

Jul–Nov 2007. Solid symbols denote sightings during conditions when useable data were collected, open symbols containing a dot denote sightings during conditions when data were unusable, and open symbols denote incidental sightings, including search and connect legs.

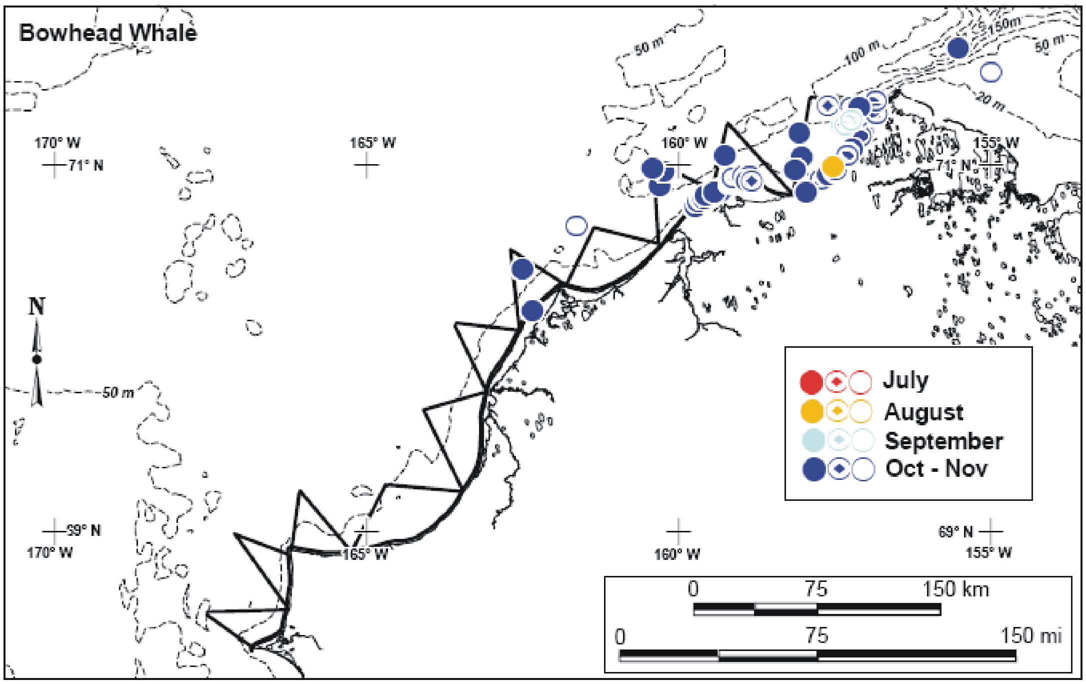

FIGURE 4.7. Locations of bowhead whale sightings during aerial surveys in the eastern Chukchi Sea during Jul–Nov 2007. See Fig. 4.6 for explanation of different symbols.

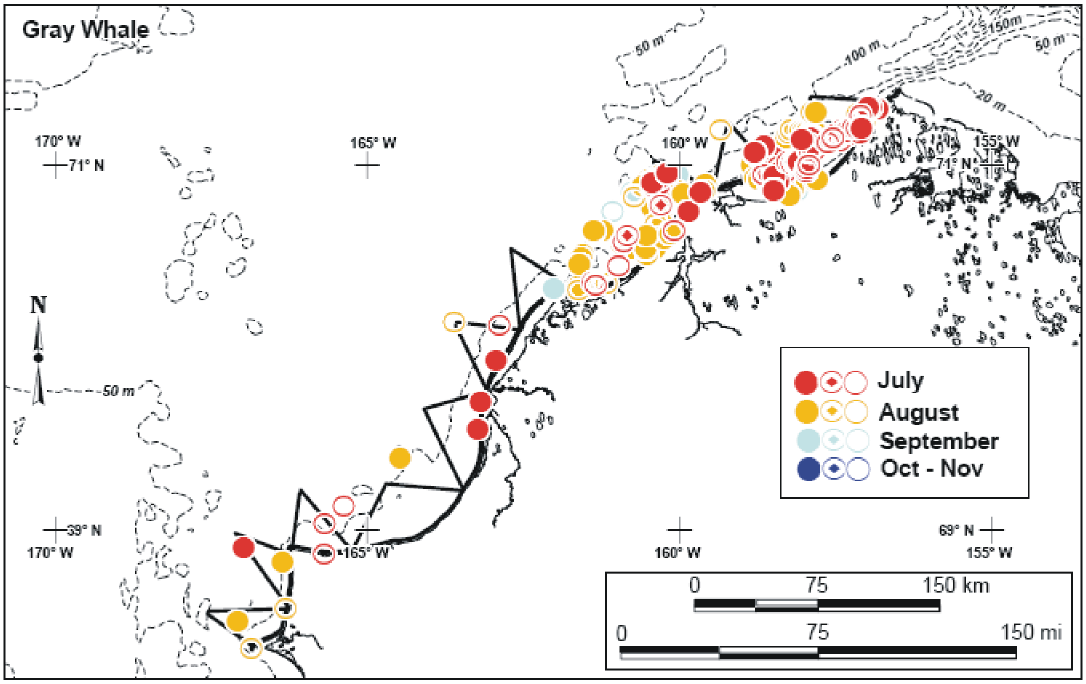

FIGURE 4.8. Locations of gray whale sightings during aerial surveys in the eastern Chukchi Sea during Jul–Oct 2007. See Fig. 4.6 for explanation of different symbols.

Distances from Shore.—Distance–from–shore data presented in this section were calculated only from useable data as defined earlier. Most of the coastline survey effort was within a single band (–5)–5 km from shore resulting in this band having the most survey effort when combined with the sawtooth surveys (Figure 4.9). Sighting rates in each distance–from–shore category were calculated using effort values shown in Figure 4.9A,B.

The highest beluga whale sighting rates were recorded in the 25–35 km band in both 2006 and 2007 (Figure 4.10A,B). The greatest number of individual belugas was recorded in the same 25–35 km band in 2007, but more individual belugas were recorded in the (–5)–5 km band in 2006 (Figure 4.10A,B). The higher numbers in the nearshore band in 2006 were due to a large group of 295 animals seen in early Jul during the coastline surveys. When we compared sighting rate distributions between 2006 and 2007, no statistical difference was detected (K–S Test, D–Max = 0.400, *P* = 0.309) so data from both years were combined. When we combined the 2006 and 2007 data, beluga sighting rates again peaked in the band 25–35 km from shore (4.66 sightings/1000 km or 7.50 sightings/1000 mi; Figure 4.11A). Group sizes of beluga whales were larger than for gray whales, and beluga was the most abundant cetacean recorded in the study area, with the highest sighting rate in the 25–35 km from shore band (44.0 individuals/1000 km or 70.8 individuals/1000 mi; Figure 4.11B).

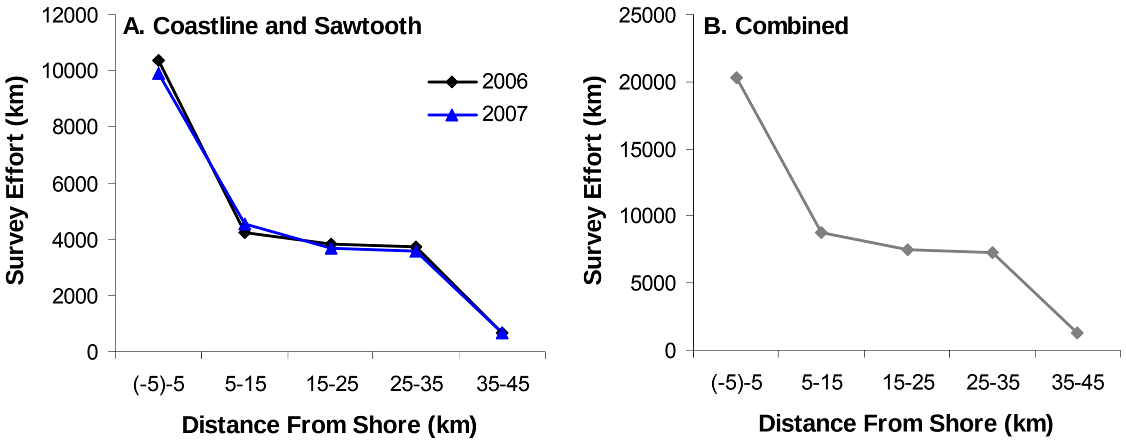

FIGURE 4.9. Cetacean aerial survey effort at various distances from shore during (**A**) combined coastline and sawtooth surveys in 2006 and 2007, and (**B**) combined 2006–07 coastline and sawtooth surveys, excluding periods of unusable data. Based on aerial surveys in the Chukchi Sea, Jul–Nov 2006–07.

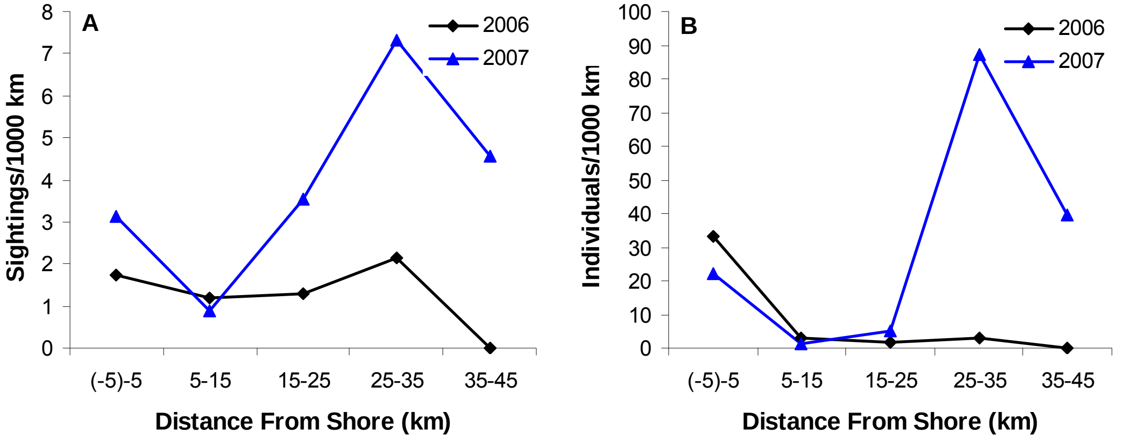

FIGURE 4.10. Distribution of beluga whales vs. distance from shore (10–km bands), excluding periods of unusable data. Figures are based on aerial surveys of the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul to Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.9A for survey effort vs. distance from shore.

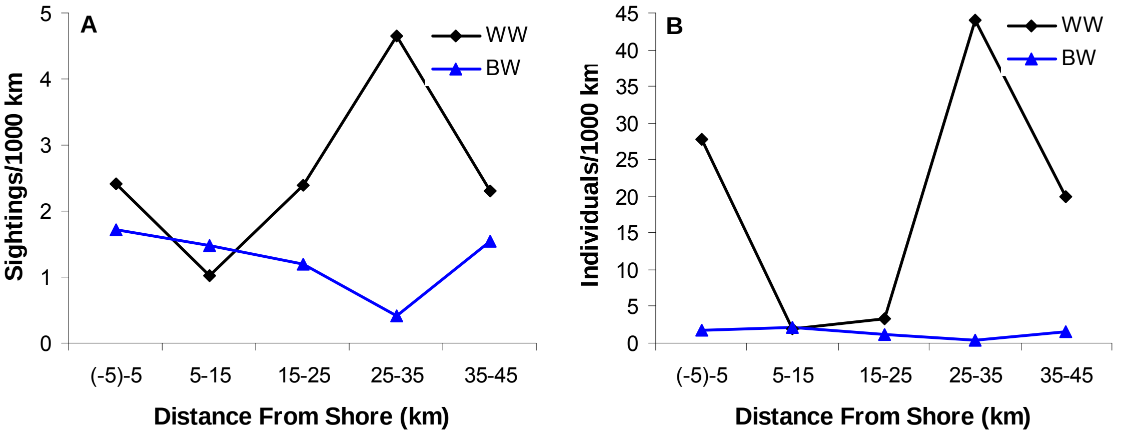

FIGURE 4.11. Sighting rates of beluga (WW) and bowhead (BW) whales vs. distance from shore (10–km bands) during the combined 2006–07 field seasons, excluding periods of unusable data. Figures are based on aerial surveys of the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul–Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.9B for survey effort vs. distance from shore.

The highest bowhead whale sighting rates and number of individuals were recorded in the (–5)–5 km band in 2007 and in the 5–15 km band in 2006 (Figure 4.12A,B). When we compared sighting rate distributions between 2006 and 2007, no statistical difference was present (K–S Test, D–Max = 0.200, *P* = 0.962) so data from both years were combined. For the combined 2006 and 2007 data set, bowhead whales had a fairly uniform distribution across the five distance–from–shore bins, but sighting rates were lower in the 25–35 km from shore bin (0.41 sightings/1000 km or 0.66 sightings/1000 mi) where beluga and gray whale sighting rates were highest. For the combined data set, bowheads sighting rates were highest in the band (–5)–5 km from shore (1.73 sightings/1000 km or 2.78 sightings/1000 mi; Figure

4.11A). The numbers of individual bowheads was fairly uniform among the distance from shore bands; the highest individual counts were recorded in the 5–15 km from shore band (2.16 individuals/1000 km or 4.18 individuals/1000 mi; Figure 4.11B).

The highest sighting rates and number of individual gray whales were recorded in the (–5)–5 km band in 2006 and in the 25–35 km band in 2007 (Figure 4.13A,B). The nearshore (–5)–5 km band had the greatest numbers of gray whales in 2006 and the least in 2007. Sighting rates in various bands from shore in 2006 vs. 2007 were significantly different (K–S Test, D–Max = 0.700, *P* = 0.006). The difference seen in the gray whale distribution between 2006 and 2007 was most likely due to differences in food availability. Gray whales were observed feeding farther offshore in 2007 than in 2006.

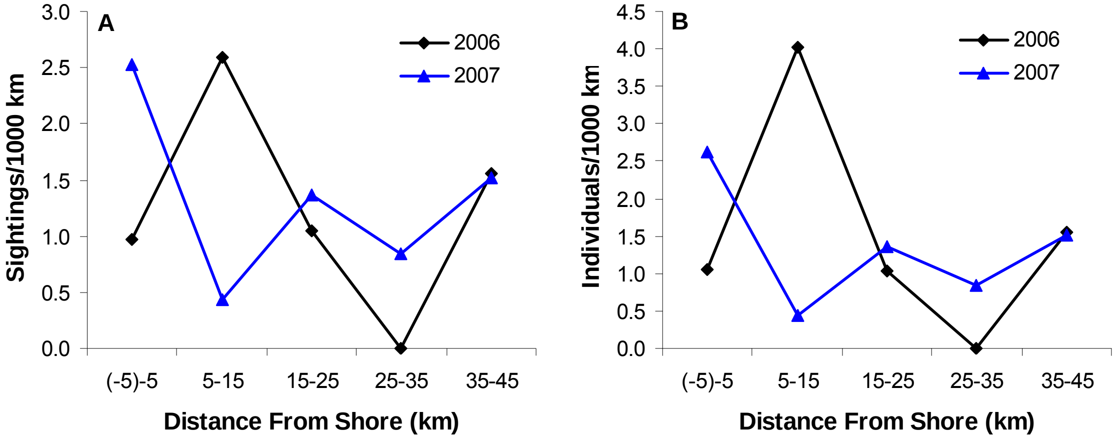

FIGURE 4.12. Distribution of bowhead whales vs. distance from shore (10–km bands), excluding periods of unusable data. Figures are based on aerial surveys of the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul to Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.9A for survey effort vs. distance from shore.

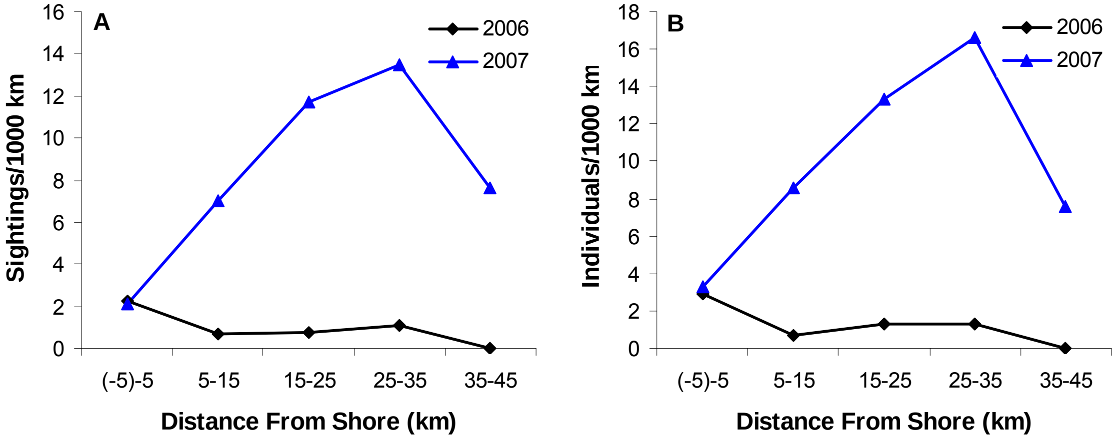

FIGURE 4.13. Distribution of gray whales vs. distance from shore (10–km bands), excluding periods of unusable data. Figures are based on aerial surveys of the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul to Nov 2006–07. (**A**) sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.9A for survey effort vs. distance from shore.

Migration Timing.—The seasonal timing of whale sightings during the study period was important in estimating the distribution of whales in the area at different times of the year. Survey effort during the five–month period from Jul through early Nov was highly variable in both 2006 and 2007 (Fig. 4.14A). When effort in the two years was combined there was a very uniform distribution of effort from Jul to Oct (Fig. 4.14B).

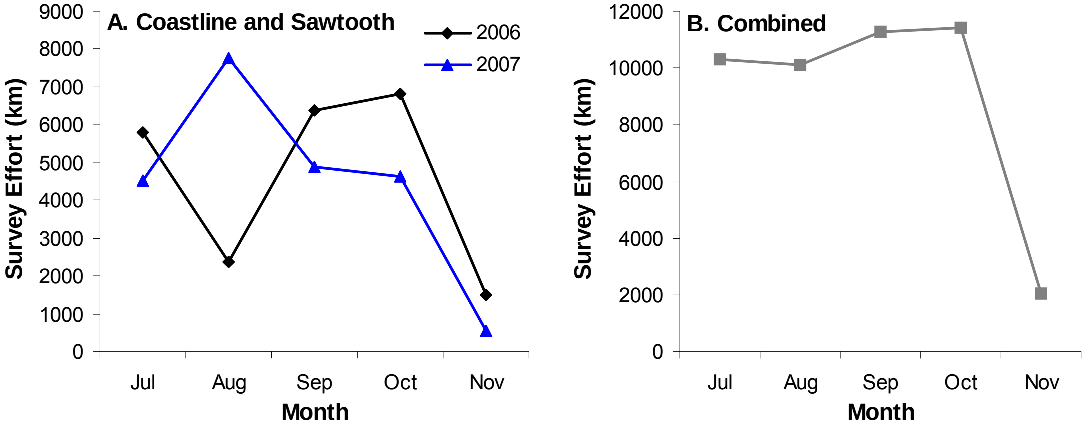

FIGURE 4.14. Cetacean aerial survey effort at monthly intervals of (**A**) combined coastline and sawtooth surveys in 2006 and 2007, and (**B**) combined 2006–07 coastline and sawtooth surveys, excluding periods of unusable data. Based on aerial surveys in the Chukchi Sea, Jul–Nov 2006–07.

Peak sighting rates and numbers of individual beluga whales were each recorded in Jul for both 2006 and 2007 (Fig. 4.15A,B). When we compared sighting–rate distributions between 2006 and 2007, no statistical difference was detected (K–S Test, D–Max = 0.444, $P = 0.307$) so data from both years were combined. When we combined the 2006–07 data, beluga whales had the lowest monthly observation rates in Sep (0.80 sightings/1000 km or 1.29 sightings/1000 mi and 1.06 individuals/1000 km or 1.71 individuals/1000 mi), and the highest monthly sighting rates in Jul (Fig. 4.16).

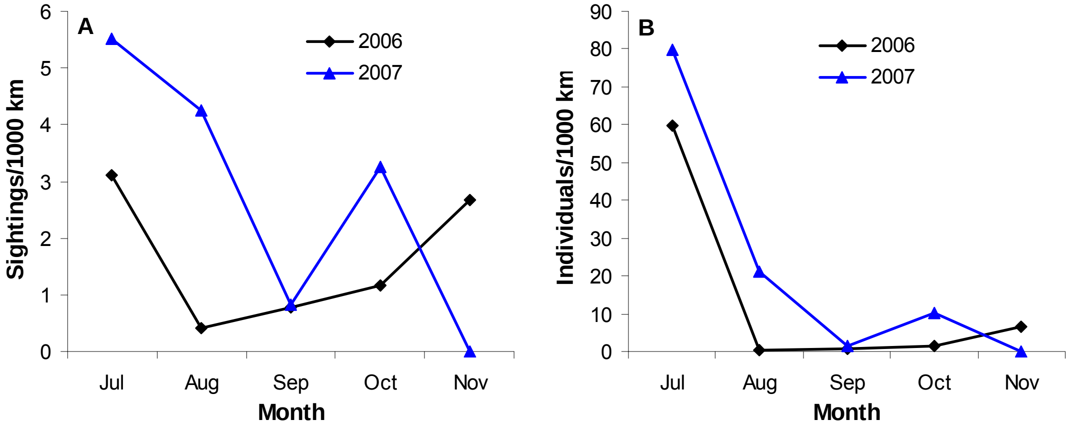

FIGURE 4.15. Seasonal pattern of beluga whale observations in 2006 and 2007 from aerial surveys in the Chukchi Sea during summer and autumn, excluding unusable data. Includes (**A**) sightings and (**B**) individuals per 1000 km of survey effort.

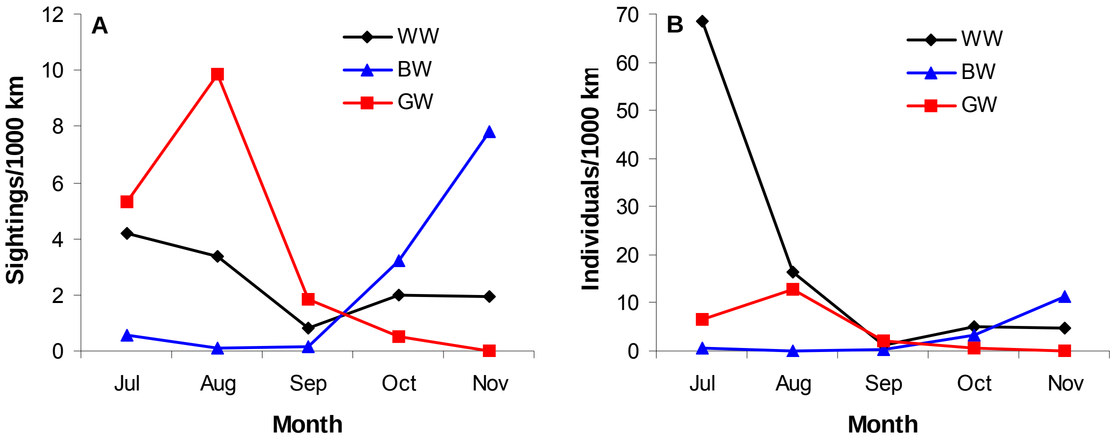

FIGURE 4.16. Seasonal pattern of beluga (WW), bowhead (BW) and gray (GW) whale observations in the combined 2006–07 field seasons, excluding periods of unusable data. Figures are based on aerial surveys of the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul–Nov 2006–07. (**A**) sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.14B for survey effort vs. month.

Peak monthly sighting rates and numbers of individual bowhead whales were recorded in Oct 2007 and in Nov 2006 (Fig. 4.17A,B). There was no statistical significant difference between 2006 and 2007 in the distribution of bowhead whale sighting rates across months (K–S Test, D–Max = 0.556, *P* = 0.111). When we combined the 2006–07 data, bowhead whales had the lowest monthly sighting rates of all three species from Jul–Sep and the highest monthly sighting rates from Oct–Nov, with the highest sighting rate in Nov (7.81 sightings/1000 km or 12.6 sightings/1000 mi; Fig. 4.16A). A similar pattern was seen with the numbers of individual/1000 km, where numbers were consistently low through Jul–Sep and peaked in Nov (11.2 individuals/1000 km or 18.1 individuals/1000 mi; Fig. 4.16B).

Peak monthly sighting rates and numbers of individual gray whales were recorded in Aug 2007 and in Jul 2006 (Fig. 4.18A,B). There was no statistically significant difference between 2006 and 2007 in the distribution of gray whale sighting rates across months (K–S Test, D–Max = 0.444, *P* = 0.307). When we combined the 2006–07 data, gray whales had the highest monthly sighting rates of all three species from Jul–Sep with their highest sighting rate in Aug (9.87 sightings/1000 km or 15.9 sightings/1000 mi) and the lowest monthly sighting rates from Oct–Nov; (Fig. 4.16A). Gray whales had the highest counts of individuals in Aug (12.7 individuals/1000 km or 20.5 individuals/1000 mi; Fig. 4.16B).

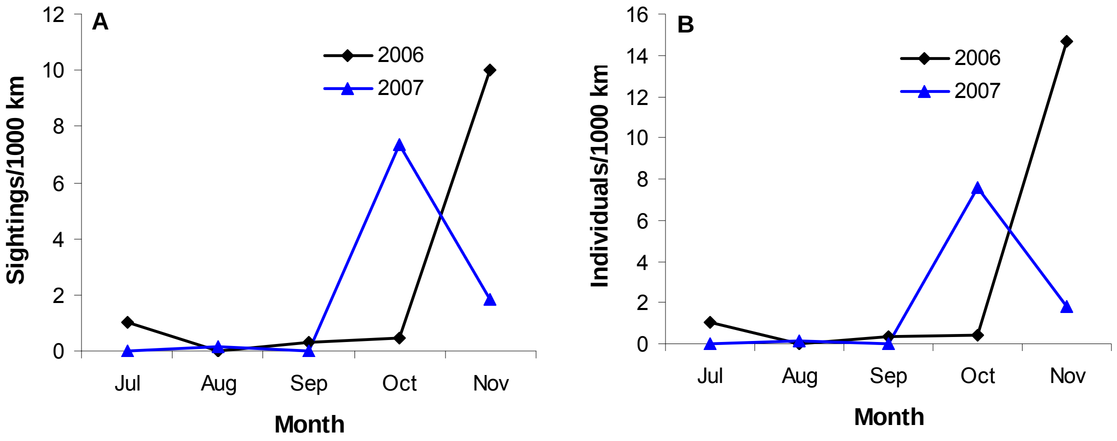

FIGURE 4.17. Seasonal pattern of bowhead whales in 2006 and 2007, based on aerial surveys in the Chukchi Sea during summer and autumn, excluding unusable data. Includes (**A**) sightings and (**B**) individuals per 1000 km of survey effort.

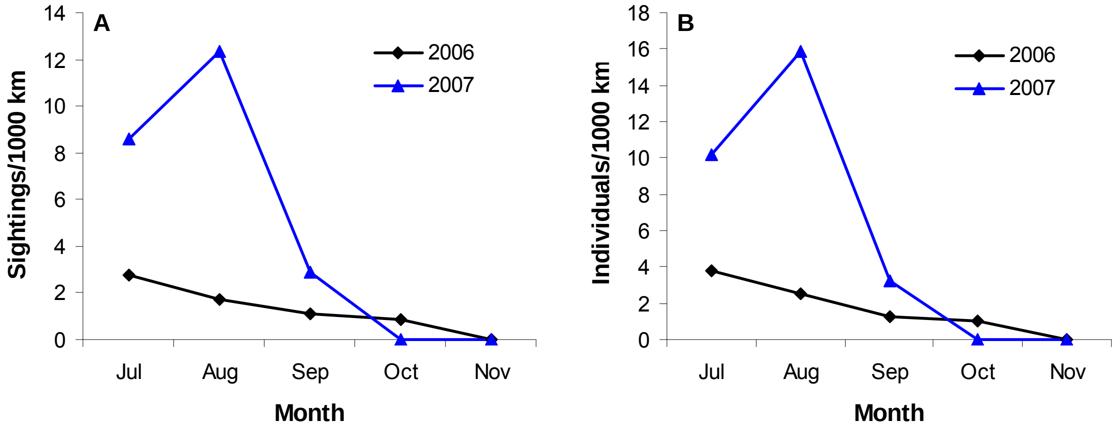

FIGURE 4.18. Seasonal pattern of gray whales in 2006 and 2007, excluding unusable data based on aerial surveys in the Chukchi Sea during summer and autumn. Includes (**A**) sightings and (**B**) individuals per 1000 km of survey effort.

Sighting rate comparisons with earlier studies— In order to compare our sighting rates with those of a previous study we divided our data into two seasons (summer for Jul through Aug and autumn for Sep through Oct). Our Nov data were excluded from this analysis to be more comparable to the Moore et al. (2000) study. Beluga whale sighting rates in the autumn and gray whale sighting rates in the summer during the current study were similar to those reported by Moore et al. 2000; Table 4.9). Gray whale sighting rates in the autumn during the earlier studies were over twice those reported in the current study, but fall bowhead sighting rates were higher in the current study.

Behavior, Swimming Speeds, and Headings—For the 2006–07 seasons combined, the predominant behavior recorded for beluga whales was traveling (86%; Table 4.10). Of the 35 sightings of traveling whales with a swimming speed recorded, five (14%) were traveling at fast speed, 13 (37%) were traveling at medium speed, and 17 (49%) at slow speed.

Based on the combined 2006–07 data, the vector mean heading of 19 beluga whales was 340°T with an angular standard deviation of 62°T (*P*<0.001) during Jul and Aug (Fig. 4.19A). This northerly heading was expected during the summer migration. The headings of 28 "traveling" individual beluga whales or beluga whale groups during the fall (Sep–Nov) produced a vector mean heading of 253°T with an angular standard deviation of 78°T (*P*=0.01; Fig. 4.19B). A mean vector heading in a southerly or westerly direction was expected during the fall migration.

TABLE 4.9. Comparison of cetacean sighting rates (sightings/1000 km) in the Chukchi Sea during the combined coastline and sawtooth surveys 2006–07 to an earlier study. Compares the combined 2006–07 data to an earlier study by season.

	Beluga	Bowhead	Gray	Data Source[a]
Seasons				
Summer[b]				
1982-1986	–	–	7.84	Moore et al. (2000)
2006-2007	3.97	0.36	7.94	Current Study
Autumn[b]				
1982-1991	1.40	1.00	2.93	Moore et al. (2000)
2006-2007	1.35	1.64	1.18	Current Study

[a] For the Moore et al. (2000) paper, data were taken from the northern Chukchi Sea area in the <35 m depth regime.

[b] Summer encompasses the months Jul through Aug, and autumn encompasses the months Sep through Oct.

TABLE 4.10. Summary of whale sighting behaviors in the Alaskan Chukchi Sea during aerial surveys, 2006–07. All data including unusable data and off–transect sightings are presented.

	Number of Sightings								
	Beluga Whale			Bowhead Whale			Gray Whale		
Behav.	2007	2006	%	2007	2006	%	2007	2006	%
Feed	0	4	5%	1	5	8%	100	14	73%
Travel	43	21	86%	29	20	65%	23	8	20%
Rest	1	4	7%	14	3	23%	8	2	6%
Dive	0	1	1%	2	1	4%	0	1	1%

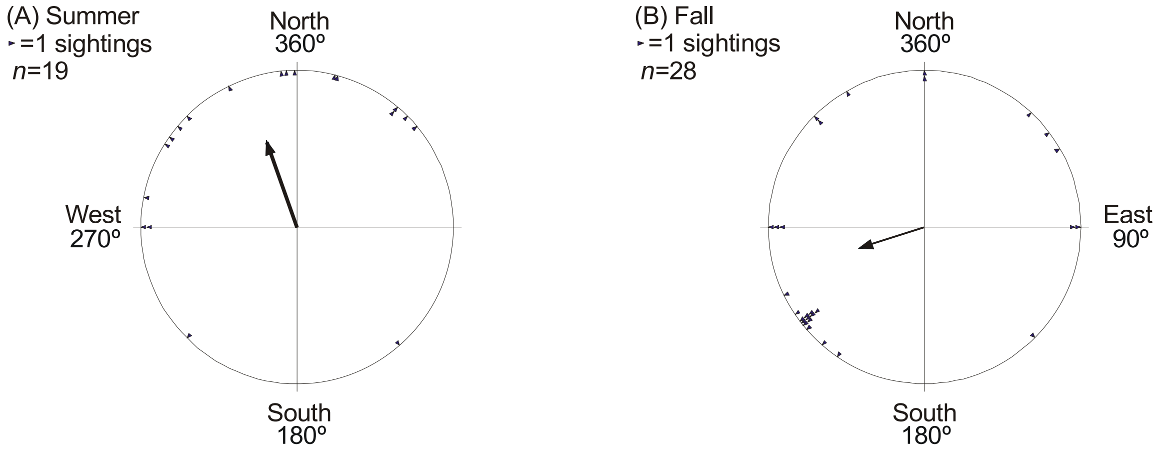

FIGURE 4.19. Headings of "traveling" beluga whales in the Alaskan Chukchi survey area during 2006–07 field seasons, comparing (A) summer, Jul through Aug and (B) fall, Sep through Nov. Figures are based on sightings during aerial surveys, including useable, unusable and off–transect sightings. Each sighting counted once regardless of the number of whales in the group.

For the 2006–07 seasons combined, the predominant behavior recorded for bowhead whales was traveling (65%; Table 4.10). Of the 27 sightings of traveling whales with a swimming speed recorded, 10 (37%) were traveling at fast speed, eight (30%) were traveling at medium speed, and nine (33%) at slow speed.

Based on the combined 2006–07 data, the vector mean heading of 36 “traveling” bowhead whales or bowhead whale groups during the fall (Sep–Nov) consisted of a uniform distribution with no predominant direction observed (Figure 4.20). The vector mean heading was 225°T with an angular standard deviation of 96°T (*P* =0.11). A mean vector heading in a westerly or southwesterly direction is what we would have expected with the fall migration. Sample size was too small to perform a test of directional trend for traveling bowhead whales in the summer (Jul–Aug).

For the 2006–07 seasons combined, the predominant behavior recorded for gray whales was feeding (74%); (Table 4.10). Of the 14 sightings of traveling whales with a swimming speed recorded, one (7%) was traveling at fast speed, three (21%) were traveling at medium speed, and 10 (73%) at slow speed.

Based on the combined 2006–07 data, the vector mean heading of 14 “traveling” individual gray whales or gray whale groups during the summer (Jul–Aug) consisted of a uniform distribution with no predominant direction observed (Figure 4.21A). The vector mean heading was 95°T with an angular standard deviation of 98°T (*P*=0.47). The headings of 9 “traveling” individual gray whales or gray whale groups during the fall (Sep–Nov) also consisted of a uniform distribution with no predominant direction observed (Figure 4.21B). The vector mean heading was 118°T with an angular standard deviation of 103°T (*P*=0.71).

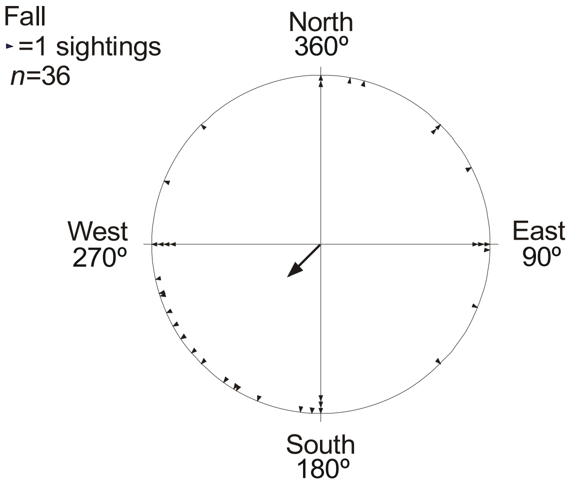

FIGURE 4.20. Headings of "traveling" bowhead whales in the Alaskan Chukchi survey area during the fall, Sep to Nov 2006–07. Figures are based on sightings during aerial surveys, including useable, unusable, and off–transect sightings; each sighting counted once regardless of the number of whales in the group.

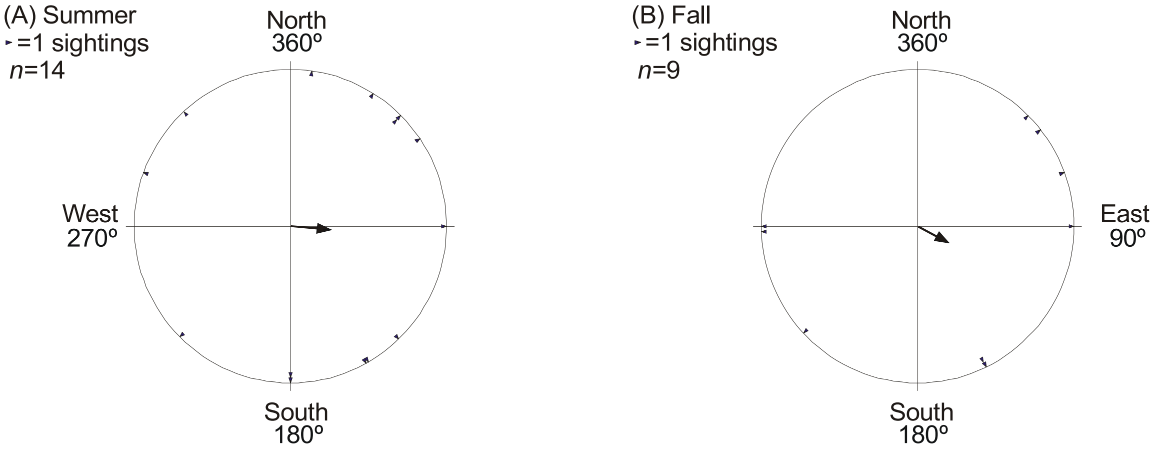

FIGURE 4.21. Headings of "traveling" gray whales in the Alaskan Chukchi survey area during 2006–07 field season, comparing (A) summer, Jul to Aug and (B) fall, Sep to Nov. Figures are based on sightings during aerial surveys, including useable, unusable, and off–transect sightings; each sighting counted once regardless of the number of whales in the group.

Pinnipeds

Terrestrial Walrus Haulouts.—During the 2007 field season Pacific walruses were observed in large aggregations on the beaches between Barrow and Point Hope (Table 4.11, Figure 4.22). These beach haulouts represented an unusual distribution for this area, and they were believed to be the result of the lack of ice floes over their preferred shallow–water feeding grounds in the northern Chukchi Sea. During many of these observations we were able to photograph the hauled out groups to obtain a better count, but at this time the photographs have not been analyzed. The numbers in Table 4.11 are estimates that will be updated when the walruses on photographs are counted. The walruses began to arrive at beach haulouts in late Aug with the largest aggregations were observed from Sep 11 through 18. The walruses were no longer observed at beach haulouts by 9 Oct. Walruses sighted on beach haulouts were considered off–transect during the coastal and saw–tooth surveys (unusable), and were therefore not used in any of the sighting rate and density calculations.

Distribution.—During the 2007 field season, most walruses were found from Point Lay to Barrow (Figure 4.23), and large aggregations of walruses were seen at beach haulouts along the coast, with the largest aggregations concentrated between Point Lay and Wainwright. During the 2006 field season, most walruses were found in the central portion of the survey area during Jul, and were most often located in or near areas with ice floes.

Bearded seals were sighted throughout the survey area during the 2007 field season, with most sightings occurring in Oct and Nov (Figure 4.24). Bearded seal distribution was similar in 2006 but the sightings were more dispersed throughout the season.

Ringed and spotted seals were sighted throughout the survey area during the 2007 field season (Figure 4.25). A similar distribution of ringed and spotted seals was recorded in 2006.

TABLE 4.11. Location and numbers of walruses at beach haulouts on the north–western Alaskan coast observed and during aerial surveys in 2007.

Date	Time	Latitude	Longitude	Number
28-Aug-07	14:58:14	68 52.824	165 03.207	300+
2-Sep-07	14:51:28	68 53.114	166 12.138	300+
11-Sep-07	12:28:24	70 19.763	161 07.538	750+
11-Sep-07	12:44:02	70 18.844	161 37.875	1500+
11-Sep-07	12:47:54	70 20.312	161 55.697	200+
11-Sep-07	12:53:42	70 12.695	162 19.816	1500+
11-Sep-07	13:12:38	69 51.564	162 55.852	1500+
18-Sep-07	17:53:56	70 12.833	162 15.405	1500+
18-Sep-07	18:18:10	70 19.451	161 06.948	1000+
18-Sep-07	19:15:47	70 54.318	157 41.451	200+
19-Sep-07	16:20:50	68 52.996	165 06.278	200+
21-Sep-07	13:48:55	70 19.583	161 07.041	100+
2-Oct-07	15:42:07	70 54.055	157 42.460	500+
3-Oct-07	15:21:13	70 55.231	157 39.402	500+
8-Oct-07	14:15:00	70 54.055	157 42.460	800+
9-Oct-07	16:56:11	70 54.055	157 42.460	200+

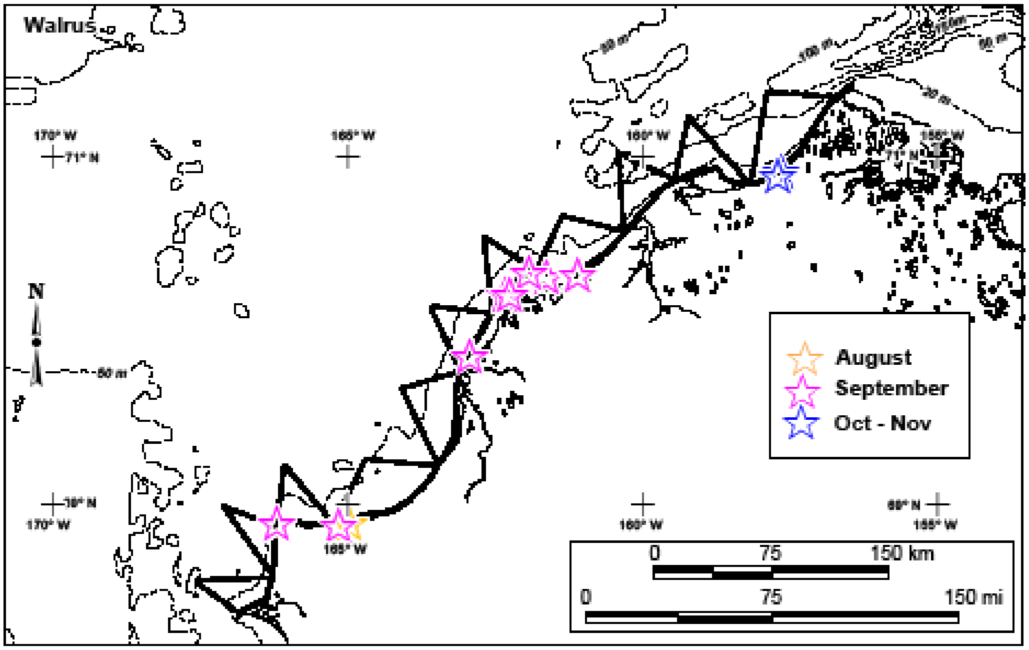

FIGURE 4.22. Locations of Pacific walrus beach haulouts during aerial surveys in the eastern Chukchi Sea during Jul–Nov 2007. Imbedded picture in top left corner was photographed on 11 Sep 2007 at 12:53:42 during aerial surveys in the eastern Chukchi Sea.

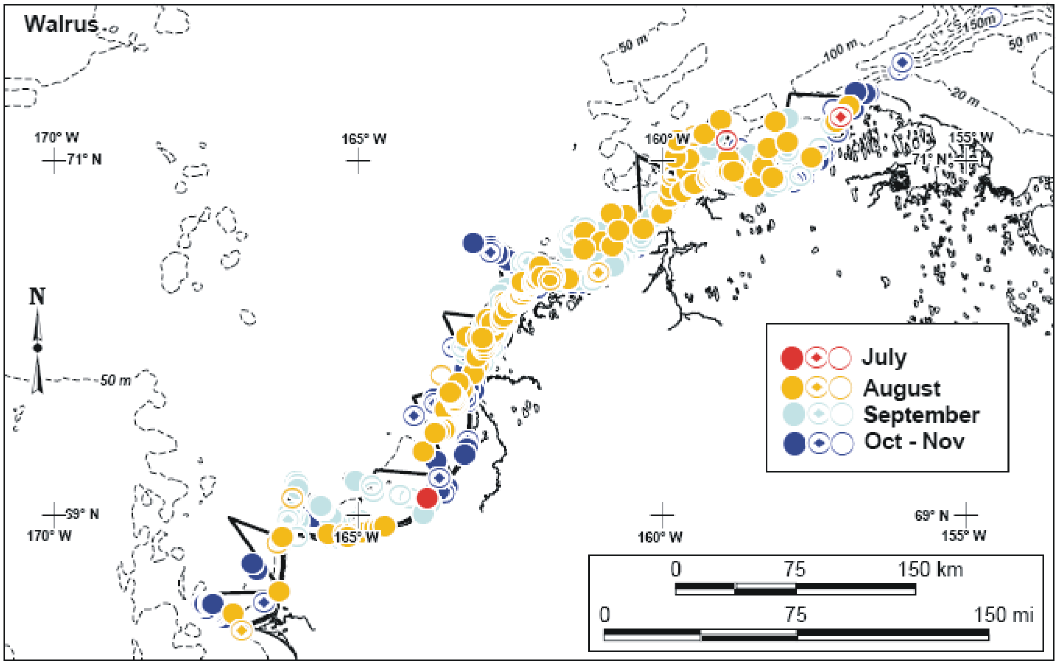

FIGURE 4.23. Locations of walrus sightings during aerial surveys in the eastern Chukchi Sea during Jul–Oct 2007, during all sighting conditions (useable, unusable, and incidental). See Fig. 4.6 for explanation of different symbols.

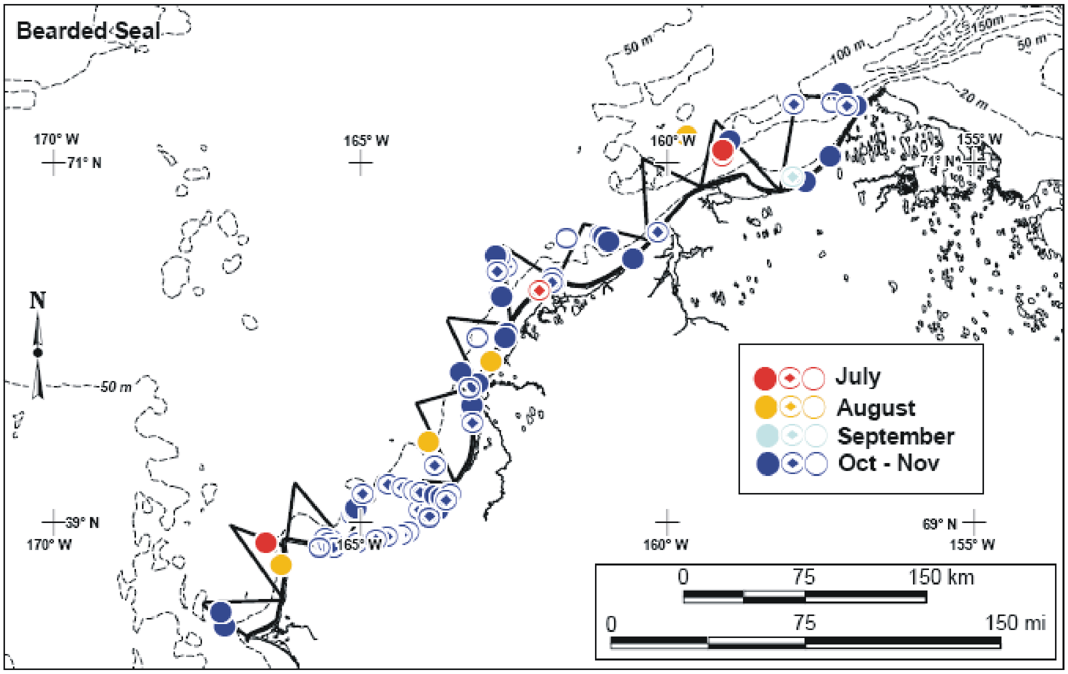

FIGURE 4.24. Locations of bearded seal sightings during aerial surveys in the eastern Chukchi Sea during Jul–Oct 2007, during all sighting conditions (useable, unusable, and incidental). See Fig. 4.6 for explanation of different symbols.

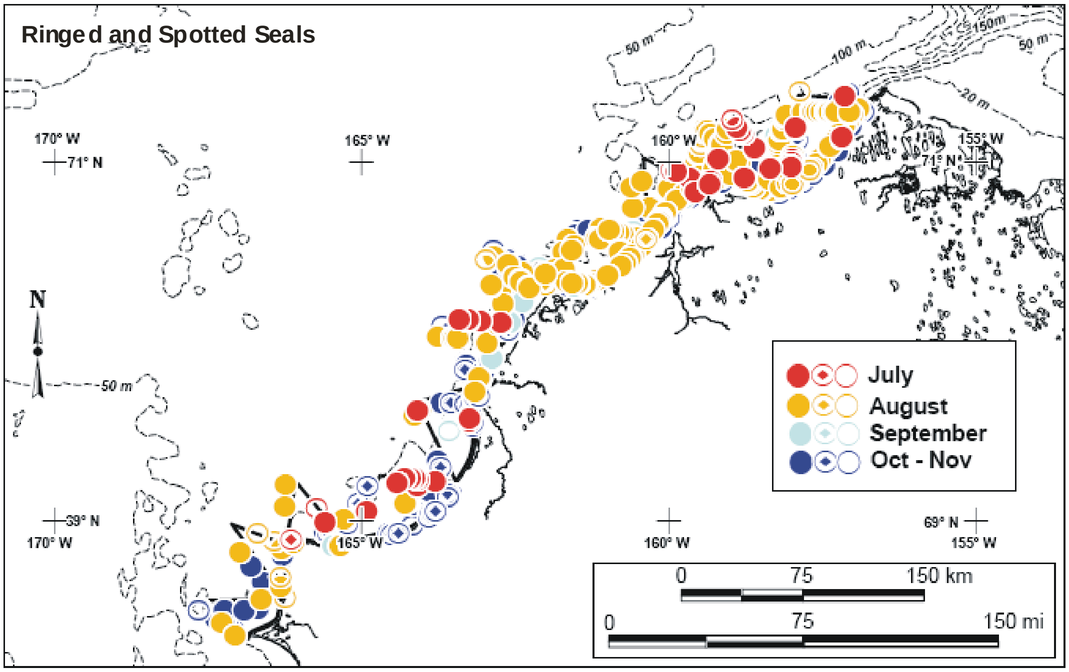

FIGURE 4.25. Locations of ringed and spotted seal sightings during aerial surveys in the eastern Chukchi Sea during Jul–Oct 2007, during all sighting conditions (useable, unusable, and incidental). See Fig. 4.6 for explanation of different symbols.

Distances from Shore.—The distribution of pinniped sightings was of interest to some stakeholders and therefore examined in this section. However, the pinniped data should be viewed with caution due to the difficulty of observing and identifying seals at survey altitudes of 305 m (1000 ft) ASL. Distance–from–shore data presented in this section were calculated in the same manner as in the previous section on cetaceans. Sighting rates in each distance–from–shore category were calculated using effort values shown in Figure 4.26A,B.

The highest walrus sighting rates and number of individuals were recorded in the (–5)–5 km band in 2007 and in the 15–25 km band in 2006 (Figure 4.27A,B). When we compared the distribution of sighting rates across the distance–from–shore bins between 2006 and 2007, no statistically significant difference was present (K–S Test, D–Max = 0.500, *P* = 0.112). However, we did not believe it was appropriate to combine data from the two years because categorizing the beach haulout sightings as unusable would heavily bias the data. The high number of walrus sightings in the (–5)–5 band in 2007 was likely a direct result of the large beach haulouts causing a constant movement of animals from the beaches to the feeding grounds. Large ice pans in the 15–25 km band in 2006 likely resulted in the relatively high walrus sighting rates within this band in 2006.

Sighting rates and numbers of individual bearded seals were highest in the band 15–25 km from shore in 2007 and in the band 5–15 km from shore in 2006 (Figure 4.28A,B). The distribution of sighting rates across the distance–from–shore bins was statistically different in 2006 vs. 2007 (K–S Test, D–Max = 0.700, *P* = 0.006). The difference in bearded seal distribution between 2006 and 2007 may have been related to the different distributions of ice and food availability between the years.

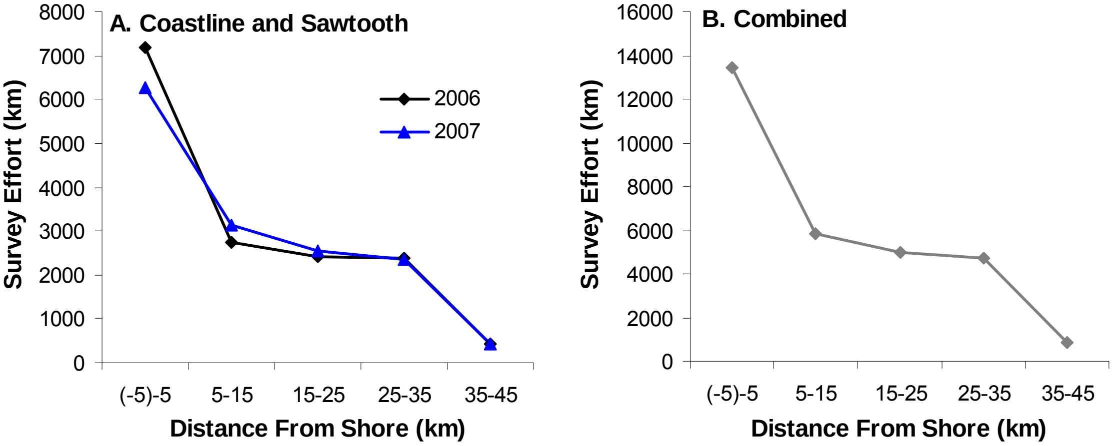

FIGURE 4.26. Pinniped aerial survey effort at various distances from shore of (**A**) combined coastline and sawtooth surveys in 2006 and 2007, (**B**) combined 2006–07 coastline and sawtooth surveys. Unusable data excluded. Based on aerial surveys in the Chukchi Sea, Jul–Nov 2006–07.

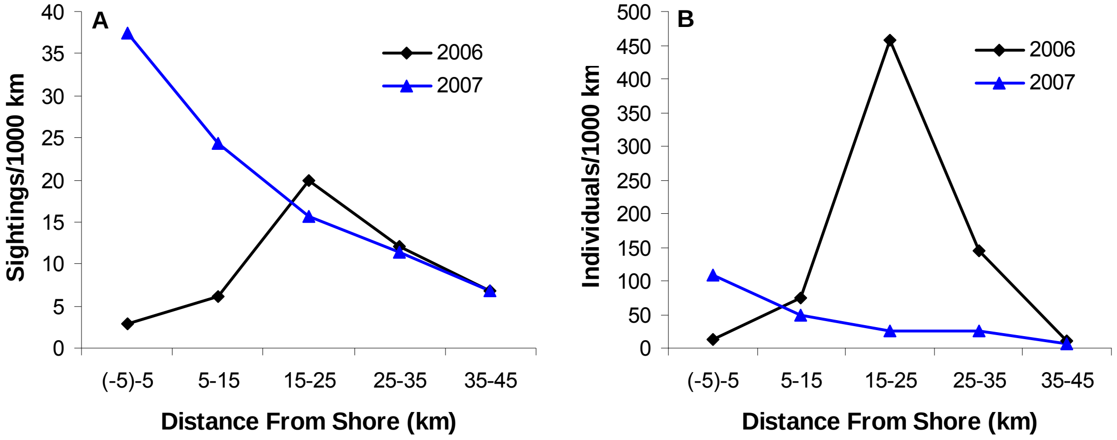

FIGURE 4.27. Distribution of walrus vs. distance from shore (10–km bands), excluding periods of unusable data. Figures are based on aerial surveys of the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul through Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.26A for survey effort vs. distance from shore.

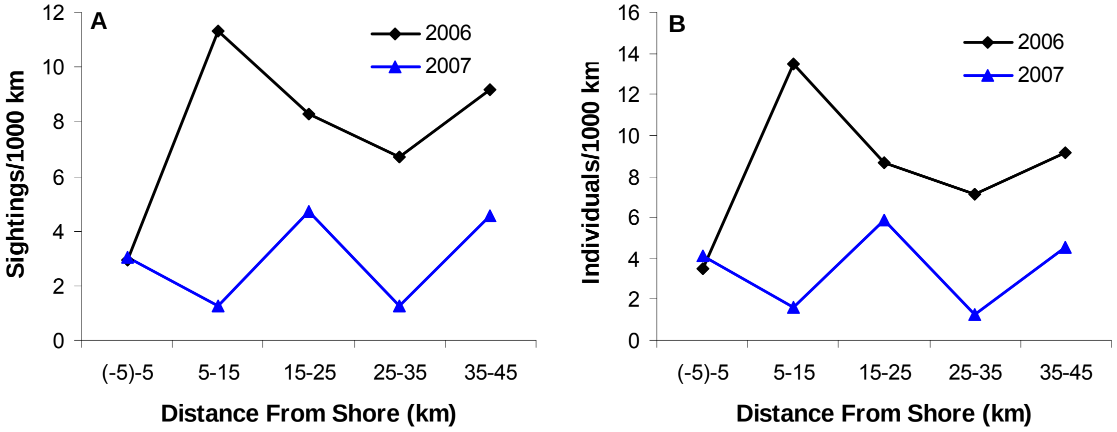

FIGURE 4.28. Distribution of bearded seals vs. distance from shore (10–km bands), excluding periods of unusable data. Figures are based on aerial surveys of both the combined coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul to Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.26A for survey effort vs. distance from shore.

Sighting rates of ringed and spotted seals were highest in the band 35–45 km from shore in both 2006 and 2007 (Figure 4.29A). The number of individual ringed and spotted seals was highest in the band 5–15 km from shore in 2007 and in the band 15–25 km from shore in 2006 (Figure 4.29B). When we compared sighting rate distribution across distance–from–shore bins between 2006 and 2007, no statistical difference was present (K–S Test, D–Max = 0.400, P = 0.309) so data from both years were combined. For the combined 2006 and 2007 data set, sighting rates of ringed and spotted seals were highest in the band 35–45 km from shore (39.9 sightings/1000 km or 64.2 sightings/1000 mi; Figure 4.30A). In the combined 2006 and 2007 data set, ringed and spotted seals had the highest counts of individuals in the 15–25 km from shore band (Figure 4.30B).

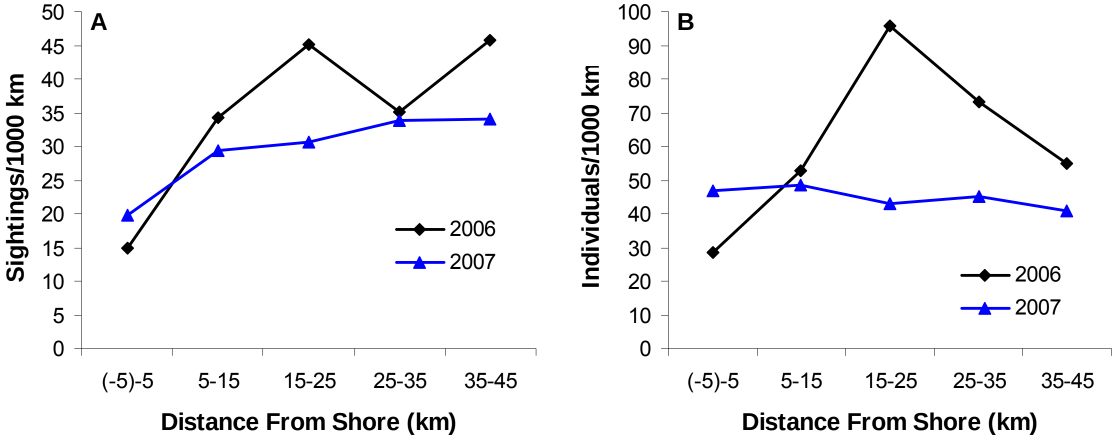

FIGURE 4.29. Distribution of ringed and spotted seals vs. distance from shore (10–km bands), excluding periods of unusable data. Figures are based on aerial surveys of both the coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul to Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.26A for survey effort vs. distance from shore.

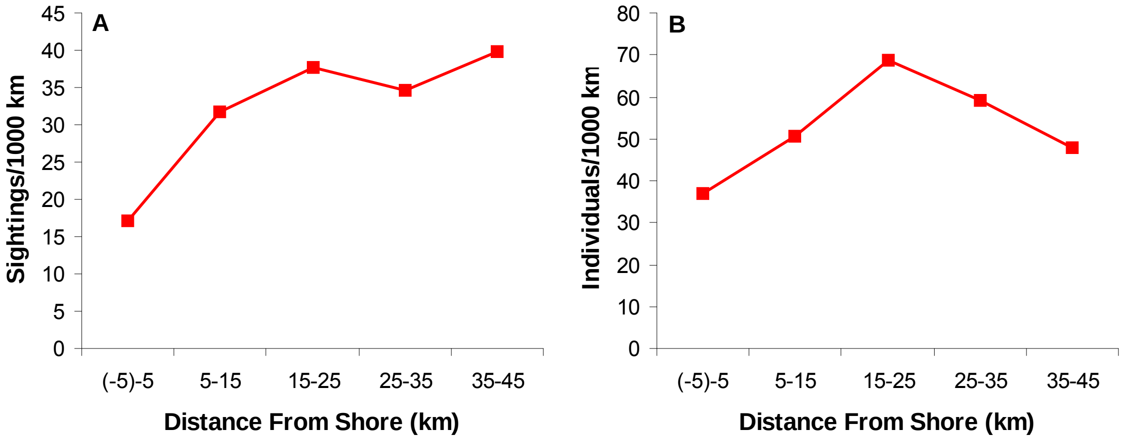

FIGURE 4.30. Distribution of ringed and spotted seals vs. distance from shore (10–km bands) in the combined 2006–07 field season, excluding periods of unusable data. Figures are based on aerial surveys of both the coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul–Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.26B for survey effort vs. distance from shore.

Seasonal Presence.—The seasonal timing of pinniped sightings was of interest to some stakeholders and therefore examined in this section. However, the pinniped data should be viewed with caution due to the difficulty of observing seals at survey altitudes of 305 m (1000 ft) ASL and apparent differences may reflect changes in survey conditions rather than actual changes in pinniped distribution or abundance. Survey coverage during the five–month period from Jul through Nov was highly variable in both the 2006 and 2007 field seasons (Fig. 4.31A). When data for the two years were combined there was a uniform distribution of effort between Jul and Sep with effort declining in Oct and Nov (Fig. 4.31B) due to deteriorating weather conditions and shorter periods of daylight available to conduct surveys.

Peak monthly sighting rates and numbers of individual walruses were recorded in Aug and Sep of 2007 and in Jul of 2006 (Fig. 4.32A,B). The distribution of sighting rates across months between 2006 and 2007 were significantly different (K–S Test, D–Max = 0.625, *P* = 0.049). The peak sightings rates and numbers of individual walruses observed in Aug and Sep of 2007 coincided with the sightings of animals at and near beach haulouts (Table 4.11). The peak sightings rates and numbers of individual walruses observed in Jul of 2006 were coincident with large amounts of pack ice observed in and near the study area in 2006.

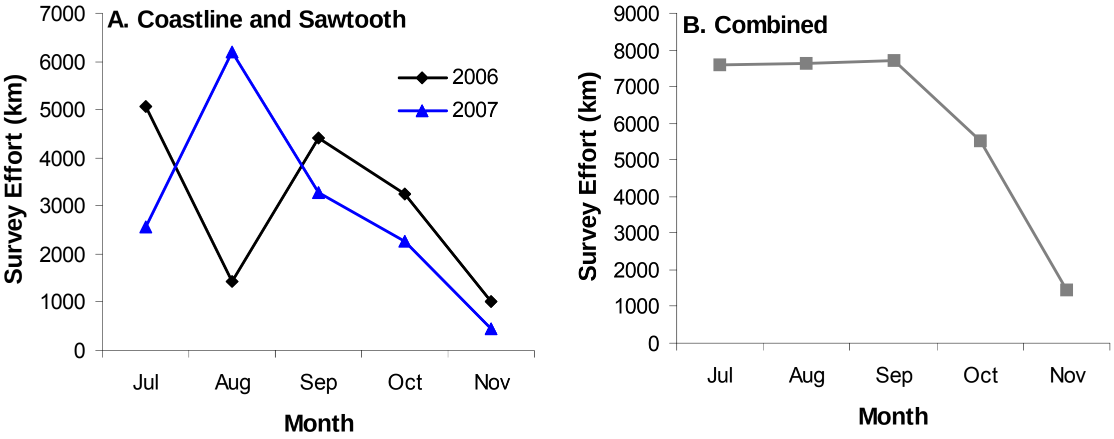

FIGURE 4.31. Pinniped aerial survey effort at monthly intervals of (**A**) combined coastline and sawtooth surveys in 2006 and 2007, (**B**) combined 2006–07 coastline and sawtooth surveys, periods of unusable data excluded. Based on aerial surveys in the Chukchi Sea, Jul–Nov 2006–07.

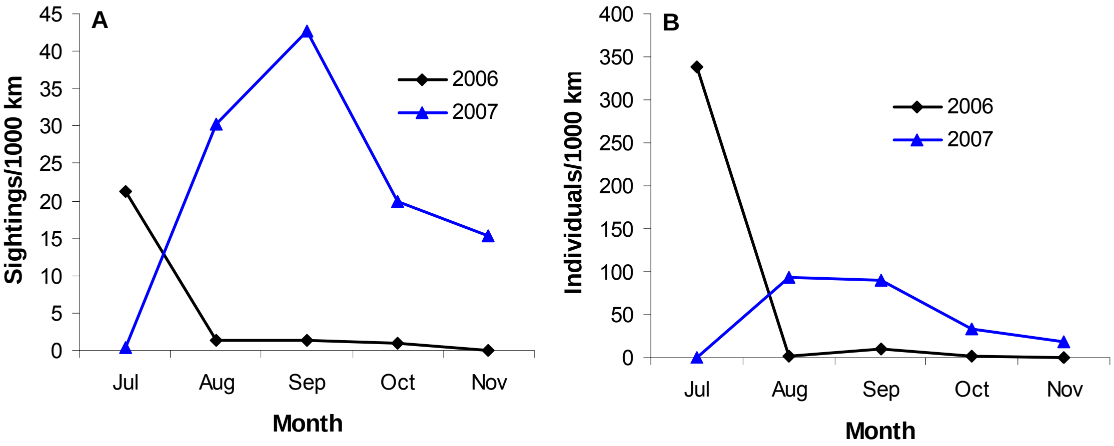

FIGURE 4.32. Seasonal pattern of walrus in 2006 and 2007, excluding unusable data based on aerial surveys in the Chukchi Sea during summer and autumn. Includes (**A**) sightings and (**B**) individuals per 1000 km of survey effort.

Peak monthly sighting rates and numbers of individual bearded seals were recorded in Nov of 2007 and in Sep of 2006 (Fig. 4.33A,B). When we compared sighting–rate distributions across months between 2006 and 2007, no statistical difference was present (K–S Test, D–Max = 0.500, *P* = 0.187) so data from both years were combined. For the combined 2006–07 data set, bearded seals had the highest monthly sighting rates in Nov and the lowest monthly sighting rates in Aug (Fig. 4.33A,B).

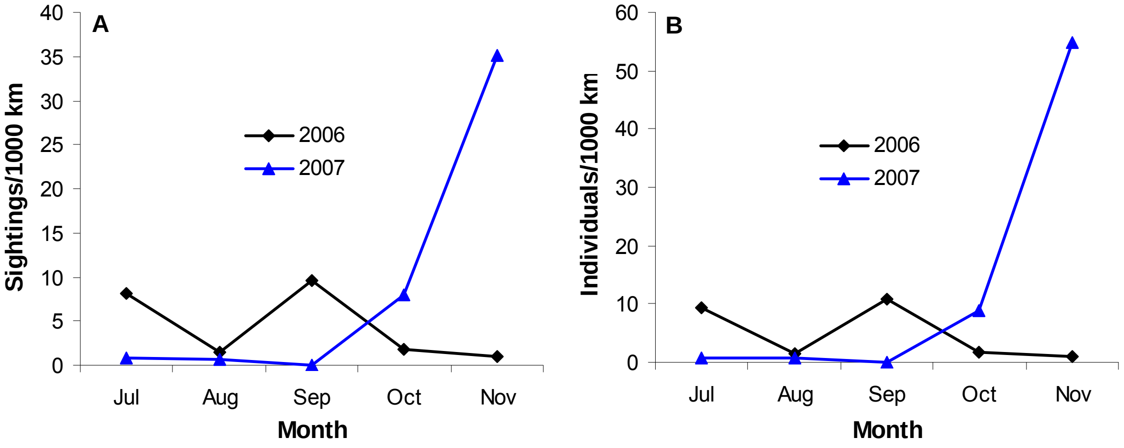

FIGURE 4.33. Seasonal pattern of bearded seals in 2006 and 2007 from aerial surveys in the Chukchi Sea during summer and autumn, excluding unusable data. Includes (**A**) sightings and (**B**) individuals per 1000 km of survey effort.

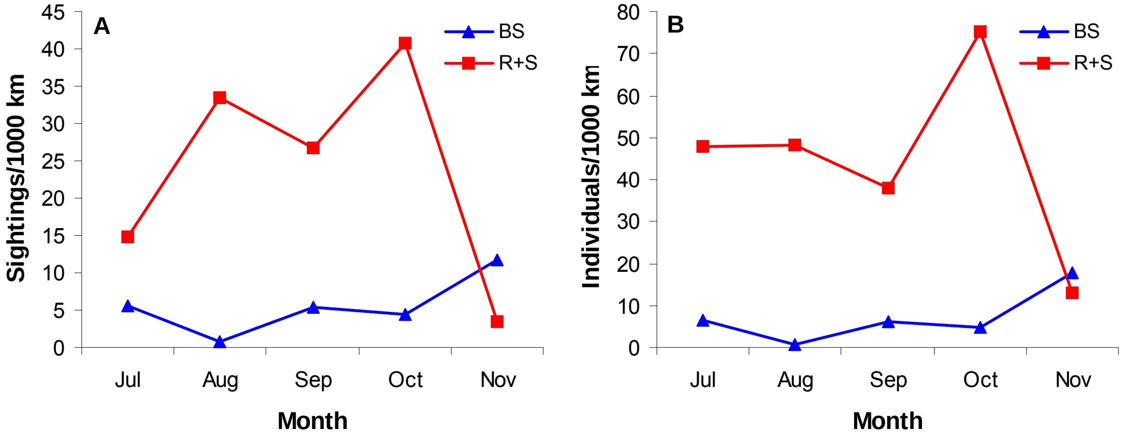

FIGURE 4.34. Seasonal pattern of bearded seal (BS) and ringed and spotted seals (R+S) during the combined 2006–07 field seasons, excluding periods of unusable data. Figures are based on aerial surveys of both the coastline and sawtooth transects in the Alaskan Chukchi Sea, Jul–Nov 2006–07. (**A**) Sightings and (**B**) individuals per 1000 km of survey effort. See Fig. 4.30B for survey effort vs. month.

Peak monthly sighting rates and numbers of individual ringed and spotted seals were recorded in Oct of 2007 and in Sep of 2006 (Fig. 4.35A,B). When we compared sighting rate distributions across months between 2006 and 2007, no statistical difference was detected (K–S Test, D–Max = 0.125, *P* =

1.000) so data from both years were combined. When we combined the 2006–07 data, ringed and spotted seals had the highest monthly sighting rates and numbers of individuals in Oct (Fig. 4.34A,B).

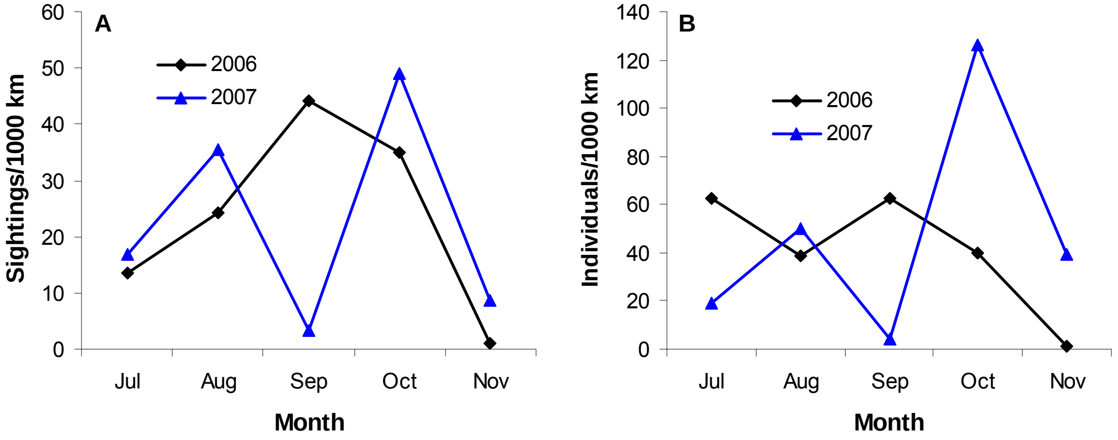

FIGURE 4.35. Seasonal pattern of ringed and spotted seals in 2006 and 2007, excluding unusable data based on aerial surveys in the Chukchi Sea during summer and autumn. Includes (**A**) sightings and (**B**) individuals per 1000 km of survey effort.

DISCUSSION

Beluga whales were estimated to be most abundant along the coastline of the eastern Chukchi Sea during Aug in 2007 and during Jul in 2006. Abundance estimates for the nearshore area covered by the sawtooth surveys were greatest during Jul in both years. Most beluga whales winter in the Bering Sea and migrate north through the Chukchi Sea in the spring to summer feeding grounds in the Canadian Beaufort Sea before returning to the Chukchi Sea in the fall. Moore et al. (1993) reported migrating beluga whales along the Chukchi Sea coast in Apr and May. Some beluga whales also congregate in the Chukchi Sea in summer (Jun–Jul), although many of these whales may also migrate north into the pack ice and east into the Canadian Beaufort Sea (Suydam et al. 2001; 2005). Based on the late–summer and early–fall distributions, there may be overlap between the Chukchi and Beaufort sea beluga whale stocks at that time of year.

When 2006–07 data from the combined coastal and sawtooth surveys were considered, the higher sighting rates for beluga whales in the Chukchi Sea during Jul–Aug and Oct–Nov were consistent with beluga migratory patterns during earlier studies (Suydam et al. 2001; 2005). Sighting rates and numbers of individual beluga whales were lowest in Sep and steadily increased in Oct and Nov. However, the numbers of individuals present at one time during the Aug–Nov period remained relatively low compared to the Jul numbers. The overall sighting rate for beluga whales was greatest in the band located 25–35 km offshore, which may be an indicator of a more dispersed beluga whale migration pattern during the fall. Clark et al. (1993) reported both nearshore and offshore components of the beluga migration in the Chukchi Sea during fall. Beluga whale sighting rates were similar in fall of 2006–07 to fall sighting rates during an earlier study by Moore (2000).

Bowhead whale abundance estimates in the nearshore Chukchi Sea were greatest during the Oct–Nov period during both 2006 and 2007. This was consistent with the bowhead whale fall migration pattern. There was a mean southwesterly compass heading for migrating bowheads during the fall period. The low number of bowhead sightings during both years may be an indication that the main migration corridor extended farther offshore than our survey area. Moore and Clarke (1993) suggested that bowheads may have a dispersed migration pattern in the northeastern Chukchi Sea during fall migration with some animals heading west to the Chukotka coast and some following the eastern Chukchi Sea coastline south. Moore et al. (1995) reported on the occurrence of bowhead whales along the northern coast of Chukotka, Russia, and suggested that these whales may have migrated to that area from the eastern Beaufort Sea. However, there is also evidence that bowhead whales seen along the Chukotka coast may be whales that spent the summer feeding in the waters north of Chukotka (Moore et al. 1995). Recent satellite data confirm that some bowheads move westward past Barrow through the Chukchi Sea to Chukotka (Quakenbush 2007) and our nearshore surveys confirm that some whales turn southward after passing Barrow and follow the east coast of the Chukchi Sea toward overwintering areas. The proportion of whales that use each of these routes is unknown and the specific fall migration routes of bowhead whales to the Bering Sea remains largely unknown. Bowhead whale sighting rates in fall in our 2006–07 surveys were higher than in an earlier study by Moore et al. (2000).

As noted above, small numbers of bowheads have been seen summering in the Chukchi Sea. We did not see bowhead whales in the nearshore Chukchi Sea during the summer in 2007 but did see small numbers during the summer of 2006. Several summer sightings of bowhead whales in the Chukchi Sea were made from vessels in 2006 and 2007 during monitoring activities for the offshore seismic program. Bowhead whale presence in the Chukchi Sea during summer was also confirmed by acoustical data in 2007 (Chapter 5).

Gray whales were more abundant in nearshore waters of the eastern Chukchi Sea during 2007 than during 2006. In 2007, they were most abundant in the northern part of the survey area from about Wainwright to Barrow. In the combined 2006–07 data, gray whales were present in nearshore waters in Jul, they increased during Aug, and decreased in Sep, with most having left by mid–Sep. No gray whales were observed after 21 Sep 2007, and most gray whales appear to have migrated out of the survey area by then. Gray whale distribution in the nearshore area was different between 2006 and 2007. Sighting rates were significantly higher in the (–5)–5 km band in 2006 and in the 25–35 band in 2007; this was most likely due to a difference in food availability. Gray whale use of foraging grounds are temporally and spatially variable (Moore 2000; Moore et al 2003), so it may be that food was more abundant closer to shore in 2006 than in 2007. Bluhm et al. (2007) suggest that frontal systems play an important role in gray whale foraging grounds. With a 50% decline in ampeliscid biomass in the northern Bering Sea since the 1980s (Coyle et al. 2007), it may be that greater variability in gray whale distribution will be observed as the recovering gray whale population seeks adequate foraging grounds. Gray whale distribution was consistent with the water–depths reported by Moore (2000), who found that gray whales in the Chukchi Sea were seen most often in coastal/shoal habitats. Gray whales sighting rates in summer during our 2006–07 study were similar to those reported in an earlier study during 1982–86 (Moore 2000). In our 2006–07 study, gray whales sighting rates were lower in autumn than during earlier studies.

The distributions and habitat use by Pacific walruses was much different in 2006 and 2007. During 2006, peak sighting rates for walruses were in Jul when they were closely associated with the pack ice. Sighting rates in the nearshore survey area declined substantially during Aug and Sep as the pack ice retreated offshore. Walruses appeared to have left nearshore areas, and presumably remained near the pack ice which was present in offshore areas. In contrast, 2007 was an exceptionally ice–free season and the pack ice retreated so far north early in the season that walruses appear to have abandoned the pack ice by late Aug to use terrestrial haulouts. In Jul 2007, when some pack ice still remained in offshore areas, walrus sighting rates in nearshore areas were lower than during Aug–Nov, which was the opposite of the pattern in 2006. During 2007, large numbers of walruses were hauled out along the Alaskan Chukchi coast during Sep. Use of terrestrial haulouts by walruses is common on the Chukotsk coast (Belikov et al. 1996), but is less common on the Alaska side of the Chukchi Sea. The large number of different haulout sites and the large numbers of walruses at terrestrial haulouts on the Alaskan side of the Chukchi Sea has not been documented before, but it may become more common if the trend of reduced ice cover in the Chukchi Sea in summer continues.

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5. CHUKCHI SEA ACOUSTIC MONITORING PROGRAM

INTRODUCTION

Shell Offshore Inc (SOI), ConocoPhillips Alaska, Inc. and GX Technology (GXT) began an acoustic monitoring program (AMP) in 2006 as part of marine mammal baseline studies for its operations in both the Beaufort Sea and Chukchi Seas. This project continued in 2007, with JASCO Research performing the AMP program for SOI in the Chukchi Sea. The goals of this program were to document the properties of received sound from exploratory operations of various types, as well as to detect vocalizations of marine mammals prior to and relative to such operations to determine potential impacts on distribution and/or migration paths.

Acoustic recorders offer the advantage that they can continuously monitor an area without attendance by personnel. The recorded data can then be analyzed to extract information from the full recorded period. The 2007 program involved deployments of thirty Ocean Bottom Hydrophone (OBH) recorders in mid-Jul 2007 over a large area of the Alaskan Chukchi Sea to record underwater sound during the summer open water period. Those OBHs were retrieved in Sep and Oct 2007. Five OBHs were redeployed in late Oct 2007 and left to record underwater sounds over the winter of 2007 – 2008.

Of particular interest to all parties is whether or not there is a change in mammal behavior in the presence of seismic activity. The design layout of OBH recorders in the Chukchi Sea was chosen primarily to help determine the region-wide distributions of several marine mammal species in the summer, and also to provide information on the migration paths of bowheads as they migrate west from the Beaufort Sea in the fall.

The thirty OBH systems originally deployed Jul-Sep recorded ambient sounds, vessel sounds, seismic sounds and large numbers of marine mammal calls. All of these data were analyzed to quantify ambient and anthropogenic (man-made) sound levels, and to determine the presence and distributions of several marine mammal species. Belugas and bowhead whales along with walrus were of primary interest during the marine mammal investigations, but gray, fin, humpback, and killer whales and various species of seals and porpoise were also detected. This chapter provides information about the methods used to acquire and analyze acoustic data and it provides results including sound levels and the locations and numbers of each type of species detected.

METHODS

OBH Systems and Deployments

Hardware Overview

The Chukchi Sea acoustic monitoring program utilized a system of autonomous Ocean Bottom Hydrophones (OBHs). The OBHs are based on AURAL-M2 acoustic recorders that are capable of making high-resolution calibrated acoustic recordings over long periods of time (up to 1 year on a duty cycle). The OBH system is normally buoyant, but while deployed it is anchored to the sea floor with weights. The OBH is retrieved by sending an acoustic command to a release unit that disconnects it from the anchor weight so it can float back to the surface. The primary OBH components include the AURAL-M2 recorder, InterOcean Systems 111-D acoustic release, recovery locator beacon, floats, anchor and frame. Figure 5.1 and Figure 5.2 show an OBH ready for deployment.

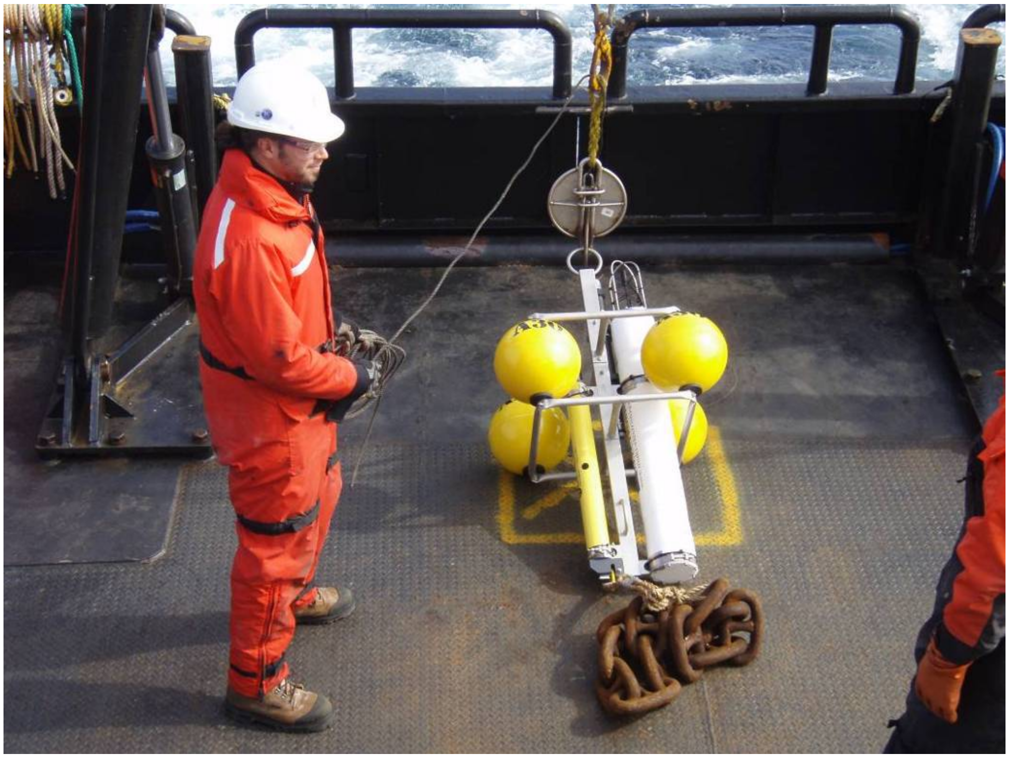

FIGURE 5.1. Ocean Bottom Hydrophone (OBH) system being deployed from the deck of the Norseman II during the 2007 Chukchi Sea acoustics study.

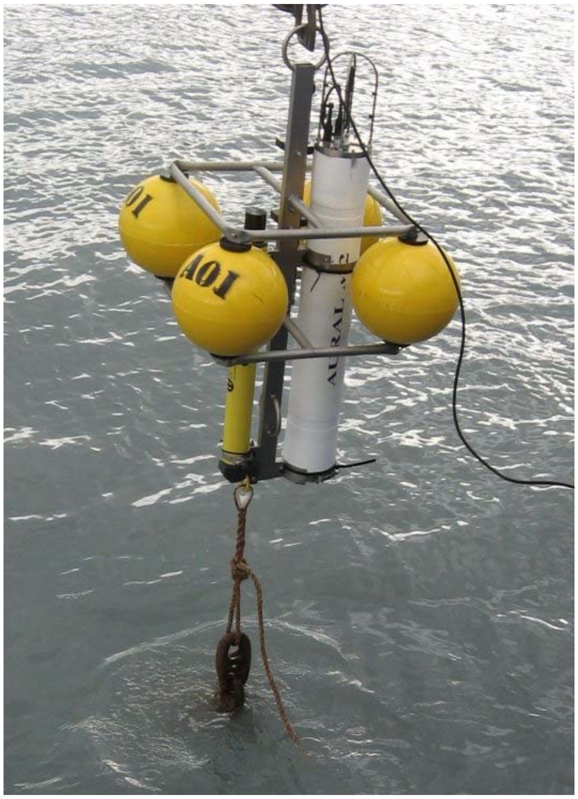

FIGURE 5.2. OBH A01 ready for deployment with anchor weight attached.

The Aural-M2 recorder has a single omni-directional hydrophone connected to a low-power recording unit and battery pack in a pressure casing. The on board electronics provide analog amplification and filtering prior to signal digitization and storage. The digital resolution is 16 bits and the sample rate is user selectable up to 32768 Hz. A sampling frequency of 16384 Hz was used for all Chukchi Sea recordings. The acoustic data are temporarily buffered in non-volatile flash memory and periodically written to hard disk. 160 GB hard disks were used for this program. The hard drive recording autonomy was approximately 55 days at the chosen sample rate of 16384 Hz. The battery pack provided approximately 160 Ah of energy (nominal), allowing for a maximum continuous recording time of approximately 75 days; disk capacity was therefore the limiting factor for length of deployment.

The InterOcean Systems model 111-D acoustic release has a maximum operating depth of 300m and a maximum load of 100 kg (220 lbs). This device securely connects the anchor weight to the OBH frame with a hinged pin, so that on deployment the OBH is sunk and held on the sea floor by the weight. When a coded acoustic signal is received by the release, a small electric motor frees the pin and disengages the anchor. The buoyancy produced by the floats then brings the OBH to the surface for retrieval.

Deployment methods, dates, locations; Phase I and Phase II

The operations plan for the Chukchi acoustic monitoring project called for two deployments of 30 OBHs. The first deployment was planned for early Jul and included near-shore OBHs to track the end of the northward beluga migration in mid-late Jul. The second deployment was planned for late Aug to allow for battery replacement and relocation of the OBHs to increase coverage in offshore areas where greater likelihood of bowhead migration was expected.

First Deployment

The M/V Norseman departed Seward, AK on 10 Jul to transit to the Chukchi Sea. Twenty-eight OBHs were deployed between 16 Jul and 20 Jul. The deployment locations are shown in Figure 5.3 and Table 5.1 below.

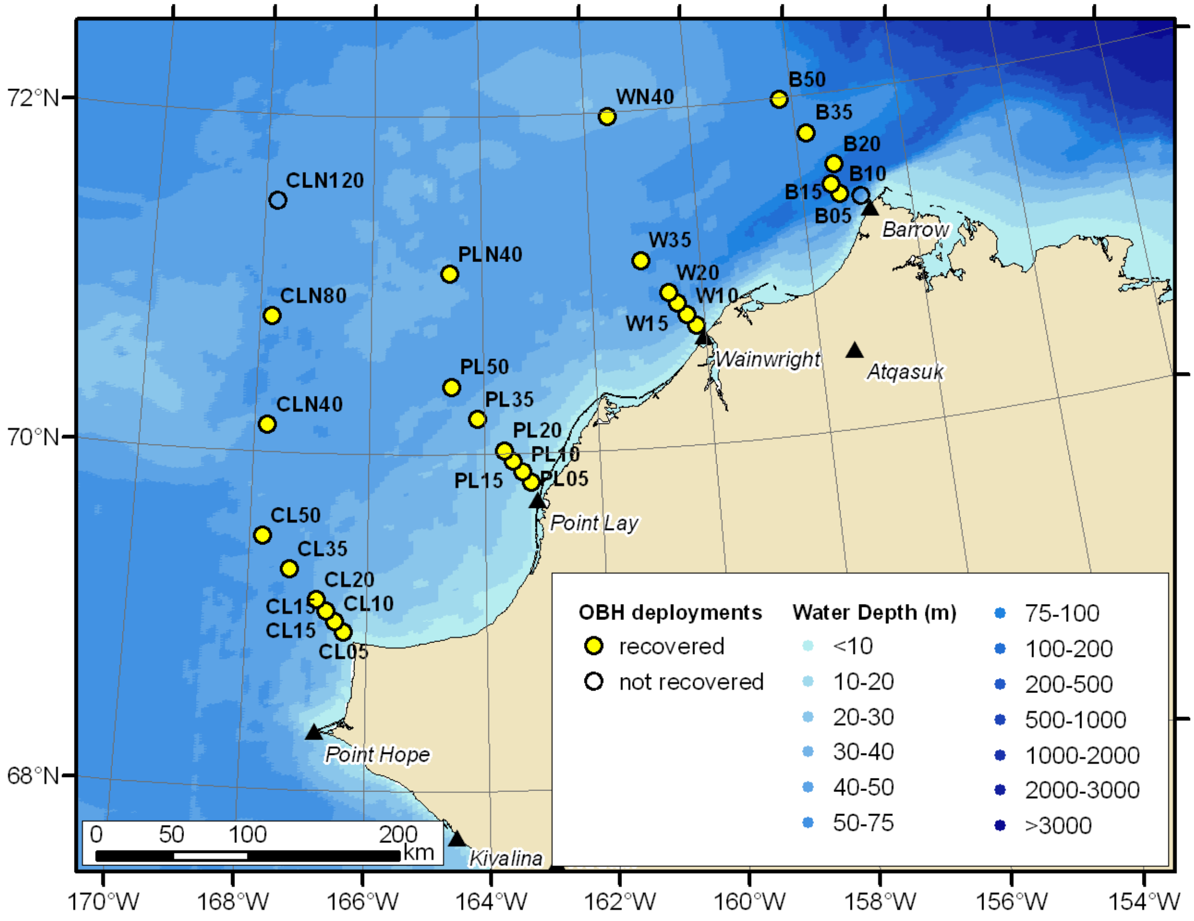

FIGURE 5.3. Deployment locations for the first deployment of the Chukchi net array.

Sub-arrays were deployed at Cape Lisburne (CL), Point Lay (PL), Wainwright (W) and Barrow (B). The 6 nearest-shore stations in each sub-array were deployed approximately perpendicular to the nominal Chukchi coast at 5, 10, 15, 20, 35, and 50 nautical miles (nmi) from the coast. The numbers in the station abbreviations (Figure 5.3) correspond to these distances in nautical miles. The remaining stations were 40, 80 and 120 nmi directly north of the stations 50 nmi (93 km) offshore. These stations are denoted by N40, N80 and N120. For example, the station 50 nmi offshore from Point Lay is labeled PL50. The station 40 nmi (75 km) north of PL50 is labeled PLN40.

OBH CL15 was recovered at the end of the deployment cruise and the first 5 days of data were downloaded for quality control purposes. It was redeployed at essentially the same location as quickly as possible. The resulting gap in the data is approximately 1 hour. The planned deployment locations at W50 and PLN80 were postponed due to ice coverage. Immediately following the deployment all Shell vessels in the Arctic were instructed to cease operations, so the two postponed deployments were omitted. Two OBHs, CLN120 and B05, could not be recovered and these data are consequently unavailable.

OBH PL35 was recovered on 26 Aug after only 39 days of deployment and before its hard drive was full (55 days capacity). All other OBHs recorded until their hard drives were full, at which time they entered standby mode until recovery.

TABLE 5.1. Deployment coordinates and data coverage intervals for the first deployment.

ID	**Station**	**Deployment position**		**Depth**	**First Record**		**Last Record**	
		N	*W*	*(m)*				
A01	CL05	68 56.343'	166 22.473'	29.3	17-Jul-07	10:59:00	13-Sep-07	06:02:18
A02	CL10	69 00.080'	166 31.504'	32.9	17-Jul-07	12:20:00	13-Sep-07	08:57:35
A03	CL15	69 03.715'	166 40.783'	36.6	17-Jul-07	13:39:00	21-Jul-07	22:03:00
A03	CL15	69 03.714'	166 40.769'	36.6	21-Jul-07	23:15:00	13-Sep-07	09:09:06
A06	CL20	69 07.688'	166 50.431'	40.2	17-Jul-07	14:43:00	13-Sep-07	08:38:34
A08	CL35	69 18.407'	167 18.354'	45.7	17-Jul-07	16:40:00	13-Sep-07	13:47:56
A05	CL50	69 29.809'	167 47.086'	45.7	17-Jul-07	18:27:00	13-Sep-07	08:35:43
A13	CLN40	70 09.471'	167 47.113'	47.5	17-Jul-07	22:22:00	14-Sep-07	09:42:36
A12	CLN80	70 48.206'	167 47.592'	54.9	18-Jul-07	02:21:00	14-Sep-07	19:56:43
A09	CLN120	71 29.180'	167 47.187'	47.5	18-Jul-07	07:21:00	not recov.	
A17	PL05	69 49.451'	163 12.175'	12.8	19-Jul-07	02:08:00	15-Sep-07	12:56:31
A18	PL10	69 53.188'	163 21.205'	20.1	19-Jul-07	01:37:00	15-Sep-07	07:43:02
A10	PL15	69 57.175'	163 30.211'	23.8	19-Jul-07	00:59:00	15-Sep-07	06:51:30
A16	PL20	70 01.089'	163 39.331'	25.6	19-Jul-07	00:35:00	15-Sep-07	06:49:46
A15	PL35	70 12.458'	164 07.152'	34.7	18-Jul-07	23:01:00	26-Aug-07	18:34:57
A14	PL50	70 23.979'	164 33.942'	42.1	18-Jul-07	21:31:00	15-Sep-07	07:38:14
A11	PLN40	71 04.022''	164 34.474'	38.4	18-Jul-07	17:09:00	15-Sep-07	04:01:55
A19	W05	70 42.255'	160 09.704'	21.9	19-Jul-07	14:19:00	12-Sep-07	11:03:20
A23	W10	70 46.317'	160 18.419'	42.1	19-Jul-07	16:55:00	12-Sep-07	15:42:24
A20	W15	70 50.451'	160 27.980'	49.4	19-Jul-07	15:54:00	12-Sep-07	19:00:47
A21	W20	70 54.605'	160 37.354'	53.0	19-Jul-07	16:26:00	13-Sep-07	13:52:40
A22	W35	71 06.598'	161 04.556'	53.0	19-Jul-07	17:58:00	13-Sep-07	17:36:33
A30	WN40	71 58.358'	161 32.304'	31.1	20-Jul-07	15:17:00	14-Sep-07	01:55:22
A24	B05	71 21.742'	156 56.290'	60.4	20-Jul-07	03:58:00	not recov.	
A25	B10	71 23.539'	157 18.680'	122.5	20-Jul-07	04:49:00	16-Sep-07	15:09:31
A26	B15	71 27.260'	157 27.353'	118.9	20-Jul-07	05:18:00	26-Aug-07	10:29:17
A27	B20	71 34.232'	157 20.977'	78.6	20-Jul-07	06:02:00	11-Sep-07	01:41:14
A29	B35	71 46.451'	157 47.830'	60.4	20-Jul-07	07:32:00	10-Sep-07	14:23:36
A28	B50	71 59.321'	158 14.243'	58.5	20-Jul-07	09:05:00	10-Sep-07	19:52:23

Second Deployment

Between 26 Aug and 14 Sep a field team recovered 9 OBHs and redeployed them, along with the two OBHs not deployed on the first cruise. The deployment locations are shown in the map and table below. The Station abbreviations have an "R" postfix denoting the redeployed positions to distinguish them from the first deployment, as some locations overlapped between the two deployments.

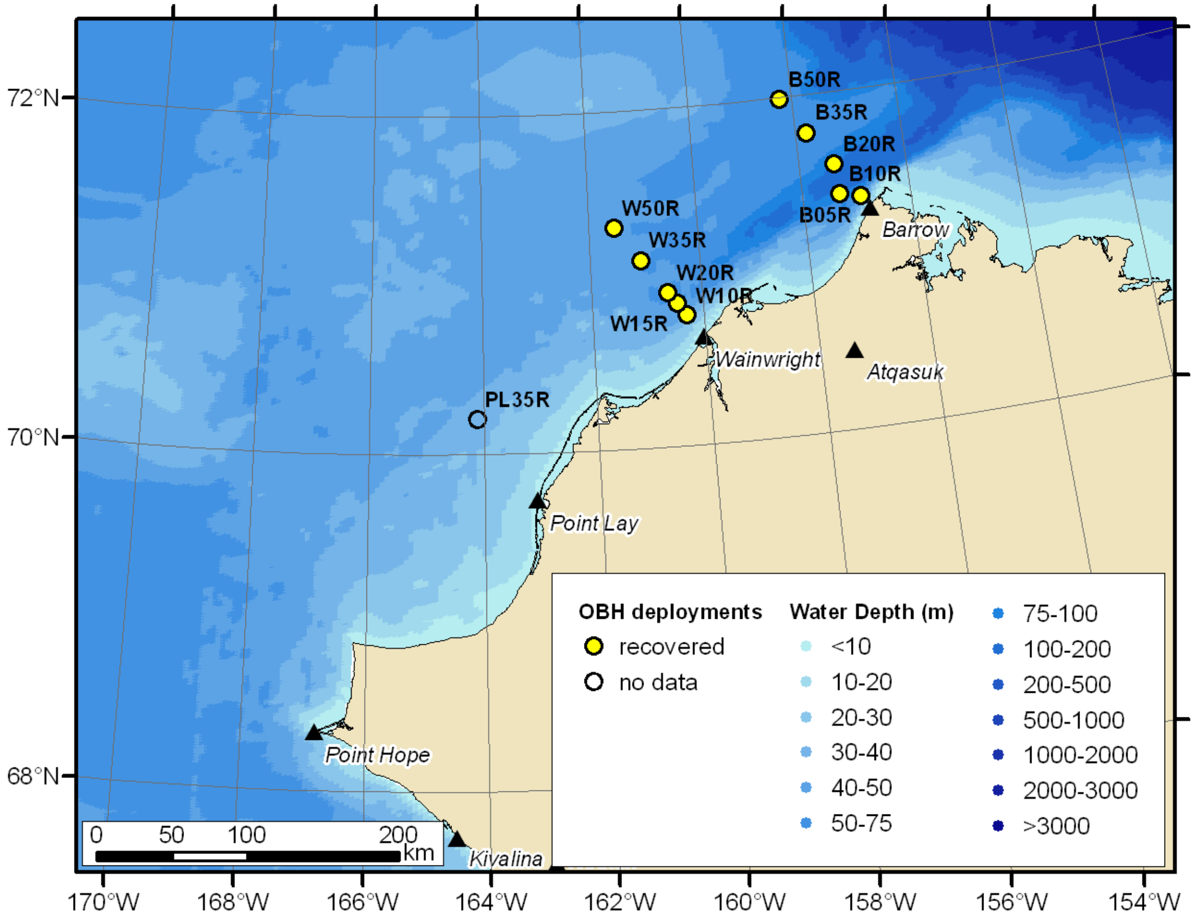

FIGURE 5.4. Deployment locations for the second deployment of the Chukchi net array.

The OBH at PL35R suffered a hardware failure and no data were recorded. Stations W10R, W15R, W20R, B05R, B10R and B20R were recovered when ice began to form near shore. Stations B35R, B50R, W35R and W50R stopped recording when their hard drives reached capacity and were recovered shortly afterwards.

TABLE 5.2. Deployment coordinates and data coverage intervals for the second deployment.

ID	**Station**	**Deployment position**		**Depth**	**First Record**		**Last Record**	
		N	*W*	*(m)*				
A07	PL35R	70 12.449'	164 07.138'	34.7	26-Aug-07	failed		
A26	W10R	70 46.328'	160 18.428'	42.1	12-Sep-07	15:47:00	19-Oct-07	22:29:17
A23	W15R	70 50.459'	160 27.980'	49.4	12-Sep-07	19:17:00	20-Oct-07	00:06:12
A20	W20R	70 54.637'	160 37.472'	53.0	13-Sep-07	13:54:00	20-Oct-07	01:38:25
A21	W35R	71 06.612'	161 04.543'	53.0	13-Sep-07	17:55:00	26-Oct-07	21:52:40
A22	W50R	71 18.653'	161 32.214'	49.0	13-Sep-07	20:01:30	25-Oct-07	19:54:54
A28	B05R	71 21.774'	156 55.977'	60.4	11-Sep-07	21:59:00	20-Oct-07	13:27:24
A30	B10R	71 23.535'	157 18.628'	122.5	14-Sep-07	12:04:00	20-Oct-07	20:31:35
A15	B20R	71 34.248'	157 20.952'	78.6	11-Sep-07	02:05:00	20-Oct-07	22:29:39
A04	B35R	71 46.454'	157 47.786'	60.4	10-Sep-07	14:09:00	26-Oct-07	12:42:06
A29	B50R	71 59.327'	158 14.224'	58.5	10-Sep-07	19:55:00	26-Oct-07	09:53:30

Overwinter Deployment

The locations of the five OBHs to be left deployed over the winter are shown in Table 5.3 and Figure 5.5. The overwinter OBHs were set on a 20% duty cycle (48 minutes out of every 4 hours), with 16 bit sampling at 16384 Hz. At this setting the hard drive space was expected to last 282 days, or approximately until the end of Jul 2008. The batteries in this configuration were expected to last longer than a calendar year, so the data storage capacity was the limiting factor. *Note: the five overwinter recorders were successfully retrieved in Aug 2008 and the data were previewed. The recorders stopped recording between 22 Jul and 3 Aug 2008. Results from these recorders are not yet available.*

TABLE 5.3. Deployment coordinates and data coverage intervals for the overwinter deployment.

ID	**Station**	**Deployment position**		**Depth**	**First Record**		**Last Record**
		N	*W*	*(m)*			
A26	PL50W	70 23.9794	164 33.9426	41.9	21-Oct-07	17:45	
A27	PLN40W	71 04.0222	164 34.4752	40.0	21-Oct-07	23:30	
A28	PLN60W	71 23.9337	164 35.2472	44	22-Oct-07	02:32	
A23	W50W	71 18.6390	161 32.2463		25-Oct-07	19:57	
A20	WN20W	71 38.5618	161 32.2499	47	25-Oct-07	22:58	

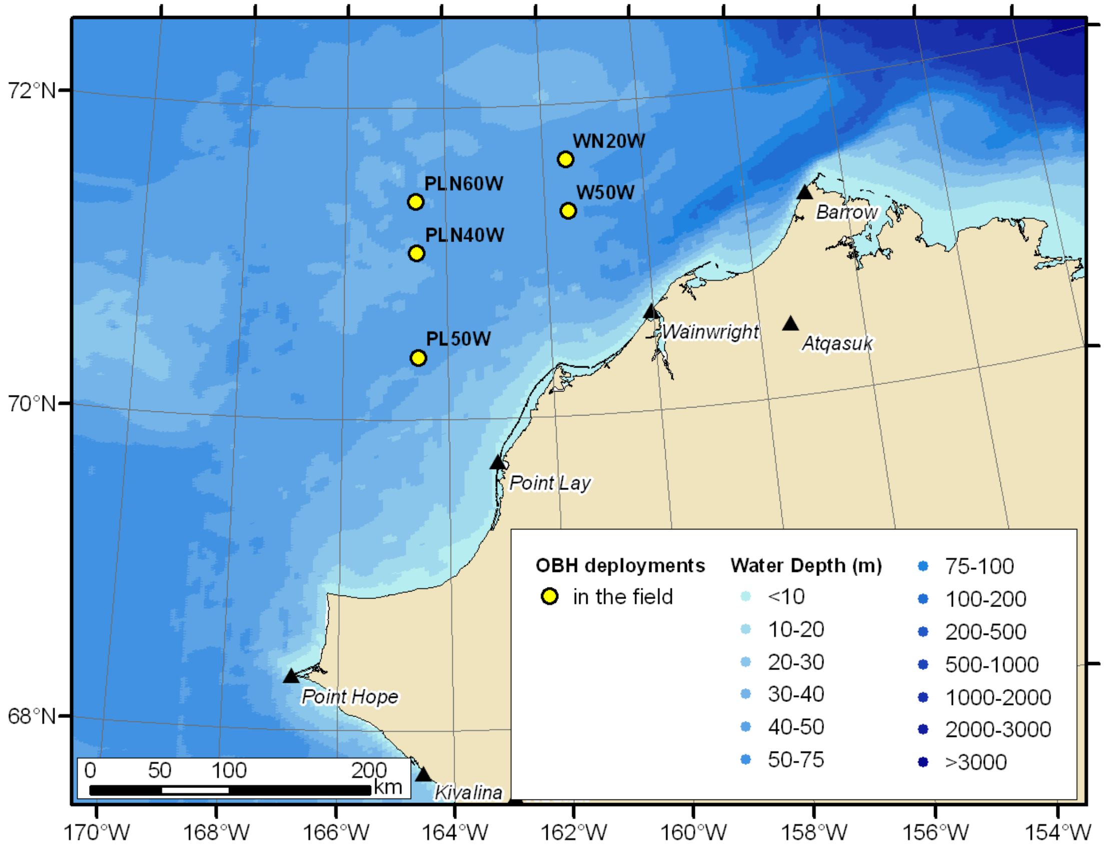

FIGURE 5.5. Deployment locations for the overwinter third deployment of the Chukchi net array.

Recovery Issues

The recovery of the Chukchi Sea acoustic net array OBHs was complicated by a manufacturing defect in many of the floats that were used to bring the units to the surface after release of the anchor weight. This failure prevented the normal recovery process and required the use of remotely operated vehicles (ROV) to physically attach a retrieval cable to each unit for direct lifting off the seafloor, a time consuming operation. As a consequence the redeployment of the Barrow and Wainwright lines was delayed and a second deployment on the Cape Lisburne and Point Lay lines did not take place.

Other Issues

Bio-fouling was present to some degree on all instruments. At most locations it was minimal, predominantly plant matter. Locations close to shore tended to have evidence of animal growth, especially barnacles. The PL05 OBH, shown in Figure 5.6, showed by far the strongest barnacle growth, with biological matter covering nearly all exposed surfaces of the OBH. It is not known whether the hydrophone calibration was affected by its near total coverage by barnacles.

FIGURE 5.6. PL5 OBH with bio-fouling by barnacles.

Analysis

The automated processing system developed by JASCO is discussed in this section. The processing consists of data preparation followed by several analysis steps that address the different objectives (seismic detections, seismic signal level, marine mammal detections, marine mammal classifications, vessel detections, and ambient levels). An overview of the processing steps is shown in Figure 5.7. In the subsections that follow, ***Data Summary*** provides a catalogue of the datasets collected; ***Data Preparation*** describes the preliminary data conditioning steps; ***Processing Overview*** describes the processing to extract the seismic, marine mammal vocalizations, and shipping events as well as the ambient SPLs; ***Processing Stream Validation*** discusses how the processing has been validated; and ***Processing Architecture*** documents how the actual implementation was performed.

Data Summary

The 2007 Chukchi Sea acoustic monitoring program produced a large quantity of acoustic and auxiliary data. There were in total more than 5 TB (note 1 TB=10^9 bytes) of data and the equivalent of 5 years of continuous sound recordings. The thirty-seven 160 GB data disk drives from the OBH recorders were backed up in the field. These data were then copied to twelve 500 GB hard disk drives that were mounted in the processing system in JASCO's offices. Each of the 79,512 data files was 62.5 MB and held just under 33 minutes of sound recording. The files were in WAV format with 16384 Hz sampling rate and 16-bit samples. The WAV files include a custom header that also contained the temperature reading from an internal temperature sensor within the OBH recorder. The temperature recorded is representative of the water temperature, and this measurement was found to be very useful for interpreting some of the ambient sound level results (see Ambient section). Tables 5.4 and 5.5 provide information about duration of recordings, number of files, and location on disk server for the data from each of the OBHs.

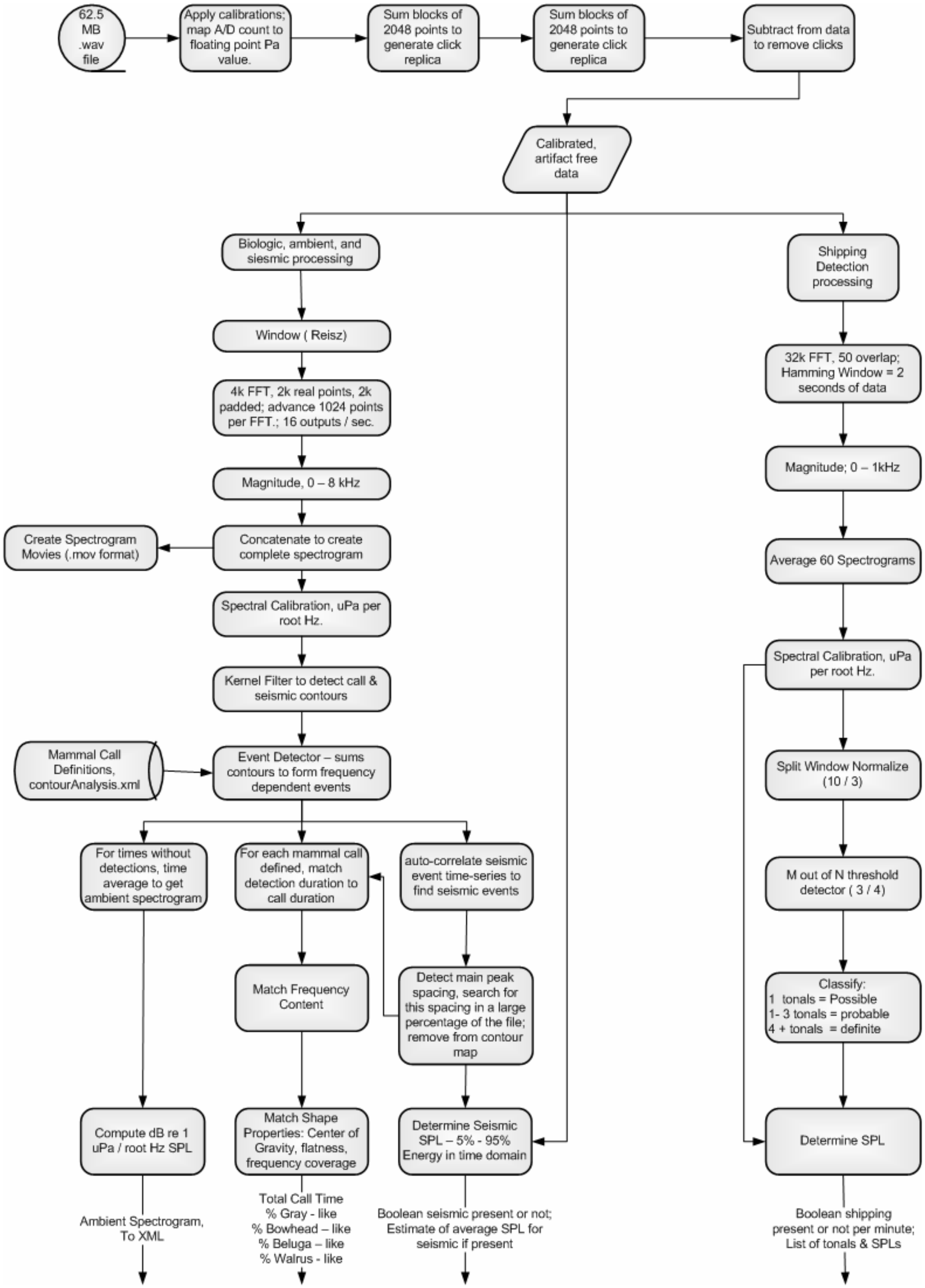

FIGURE 5.7. OBH processing block diagram.

TABLE 5.4. First deployment data storage summary.

ID	**Station**	**File Information**		
		Locations	**Number of files recorded**	**Total Data Length**
A01	CL05	D2	2493	56.38 days
A02	CL10	D7	2497	56.47 days
A03	CL15	D9	2497	56.47 days
A06	CL20	D3	2497	56.47 days
A08	CL35	D1	2497	56.47 days
A05	CL50	D1	2497	56.47 days
A13	CLN40	D2	2497	56.47 days
A12	CLN80	D10	2497	56.47 days
A17	PL05	D3	2497	56.47 days
A18	PL10	D1	2497	56.47 days
A10	PL15	D9	2497	56.47 days
A16	PL20	D7	2497	56.47 days
A15	PL35	D6	1656	37.45 days
A14	PL50	D10	2497	56.47 days
A11	PLN40	D10	2497	56.47 days
A19	W05	D4	2336	52.82 days
A23	W10	D8	2342	52.96 days
A20	W15	D8	2359	53.35 days
A21	W20	D8	2393	54.12 days
A22	W35	D1	2400	54.27 days
A30	WN40	D11	2368	53.55 days
A25	B10	D11	2497	56.47 days
A26	B15	D4	2270	51.33 days
A27	B20	D4	2263	51.17 days
A29	B35	D6	2234	50.52 days
A28	B50	D6	2244	50.75 days

TABLE 5.5. Second deployment data storage summary.

ID	**Station**	**File Information**		
		Location	**Number of Files**	**Total Time**
A07	PL35R	D7	2497	56.47 days
A26	W10R	D3	1585	35.84 days
A23	W15R	D12	1582	35.78 days
A20	W20R	D12	1559	35.26 days
A21	W35R	D12	1844	41.70 days
A22	W50R	D12	1794	40.57 days
A28	B05R	D5	1651	37.34 days
A30	B10R	D9	1656	37.45 days
A15	B20R	D11	1554	35.14 days
A04	B35R	D5	1953	44.17 days
A29	B50R	D5	1947	44.03 days

Data Preparation

The data processing stream started with a data preparation stage consisting of three steps: dynamic range checks, application of the ADC units to voltage conversion, and click removal.

As data are extracted from the WAV files their dynamic range is determined. The detection process is performed only on recordings without excessive saturation and with enough energy to detect any events. If more than 0.1% of the file duration contains saturated data points (> 32000 ADC units), then this file is discarded. Files with saturation cannot produce accurate ambient values, nor can they be used for event detections. The saturation creates impulsive events in the processed data which can be misinterpreted as a click or knock type event. Files are discarded as well if the mean variation of the recording is lower than 40 ADC units. This limited dynamic range is insufficient to ensure accurate ambient values or detection data.

The vast majority of the files passed the dynamic range tests and could be prepared for processing. The next step is to apply the voltage conversion. The ADC's in the Aural units are set for a maximum input range of 0-4 Volts and include a 22 dB preamp. As a result, the conversion from raw ADC units to voltage at the hydrophone pins is 4.85 e-6 V / unit. This value read from the auralCalibrations.csv configuration file and applied to every sample. At this point the data are also converted to a floating point value.

The data often contained a significant low frequency signal due to wave noise or slow current motions. This very low frequency signal was filtered out using a 4097 point FIR high-pass filter with -3 dB edge at 3Hz. The response was -40 dB at 0.5 Hz. The filter response is shown in Figure 5.8.

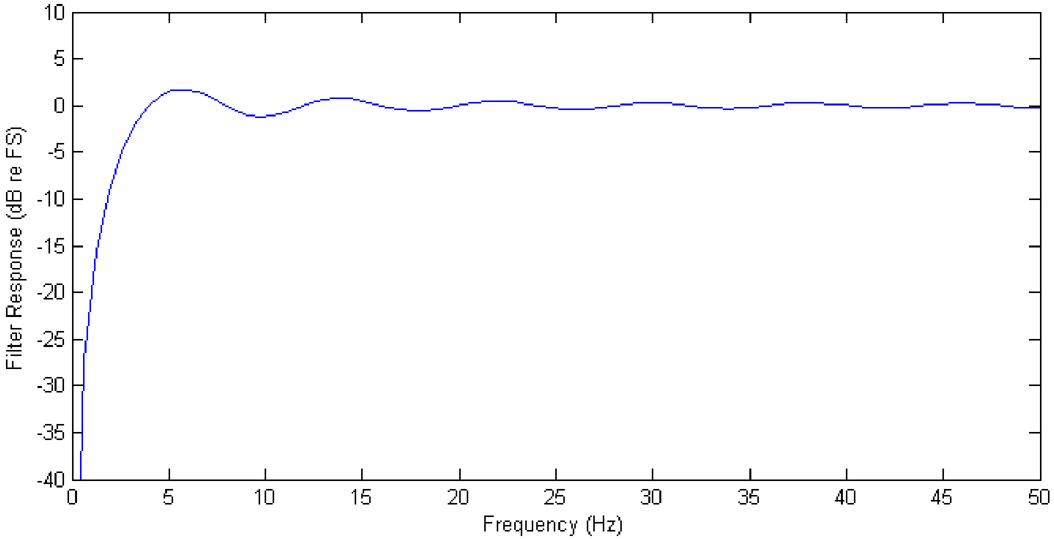

FIGURE 5.8. Frequency response of the 4097-point high pass filter.

The final step of the preparation addressed the occurrence, in some of the recordings, of evenly spaced noise pulses or clicks at 2048 sample intervals. The clicks occurred due to writing the 2048 point buffer from SRAM to flash memory within the recording unit. These clicks were extremely repeatable and reached levels of about 50 ADC units. They were effectively removed by summing every 2048 point block of data to obtain an average 'click' series which was then subtracted from the file.

Processing Overview

This section describes the algorithms that were developed to automatically analyze the recordings. The analysis approach started with a detection process to identify biologic, seismic and ship events in each segment of recording. Detected events were then analyzed to determine seismic (airgun sound) acoustic levels, classify biologic sounds, and to quantify ambient noise levels. This section provides an overview of the processing, and is supported by more detailed information in Appendix H.

Event Detection in the spectrogram

The first step of the detection process was to find all the acoustic events on the spectrogram. The spectrogram was computed using a 4096 points sliding Fast Fourier Transform (FFT). 1024 data points were included in each FFT, with an overlap of 512 points. A sample raw spectrogram is shown in Figure 5.10a. This approach is sensitive to transients on the order of 0.0625 seconds and has a frequency resolution of 4 Hz, which is appropriate for marine mammal signals.

Considerable time was spent investigating options for detecting signals in the spectrograms. Five detection methods were tested and compared: a broadband energy detector, a band-passed energy detector, a spectral entropy detector, a split window normalizer detector and a skewness based detector. These detectors are described briefly in Appendix H.

To assess the performance of the five methods described above, a dataset of test recordings containing vocalizations was assembled. This dataset consisted of acoustic recordings from the OBH at

PL35 containing beluga, bowhead and seal vocalizations. Each vocalization was manually identified and tagged by an experienced operator (Christine Erbe). The various detection methods were then tested on the dataset. In assessing a method's performance, the probability of correct detection and the probability of false alarm were computed for several values of the detection thresholds (*i.e.* by varying the parameter α for the energy and entropy detectors, and the parameter T_{swn} for the split window normalizer – see Appendix H). The results are presented on the Receiver Operating Characteristic (ROC) curves in Figure 5.9. ROC curves show probability of correct detection versus probability of false alarm. For example, a detector that just thresholds the energy of the signal (see curve with square symbols in Figure 5.9) would likely detect most events if the threshold was low, giving it a high probability of correct detection. However in that case it would also be quite likely to falsely detect non-events, giving it a high probability of false alarm. The closer the ROC curve is to the point (0,1) the better the performance. The energy detector did not have particularly good performance because as it did not approach point (0,1) on the ROC curve. Each curve shown in the ROC plot represents a different detector and the points on the curves represent the performance using different threshold values.

The detectors were run against the sample data in one minute intervals. The split window normalizer was not implemented to overlap with the adjacent time blocks, so there were eight seconds of every minute that were not processed compared to the other detectors. This is the main reason that the split window normalizer did not approach a Pd of 1.

In spite of the fact that the entropy detector outperformed the others methods, the split window normalizer was chosen to analyze the data collected in the Chukchi Sea. Two main reasons for choosing this detector were that the binary spectrogram obtained from this method was more easily used to classify the detected vocalizations, and the computation time for this method was very small.

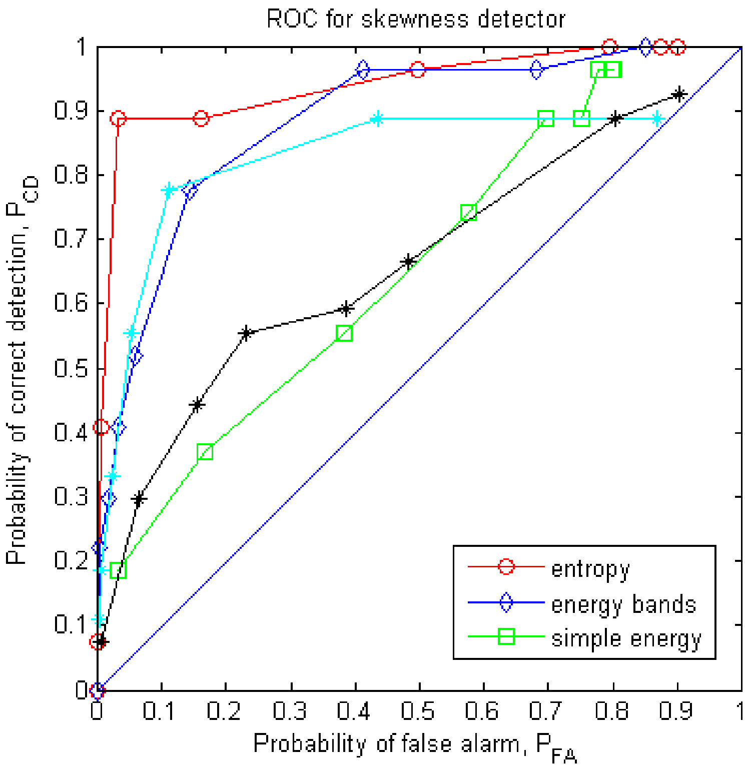

FIGURE 5.9. Receiver operating characteristics curves for detectors considered. The cyan curve (higher curve with *) is the split window normalizer, and the black curve (lower curve with *) is the skewness detector.

The split window normalizer was applied to each frequency band of the spectrogram (*i.e.* each row of the spectrogram matrix). Appendix H describes the normalization process. The normalized spectrogram is shown on Figure 5.10b. Finally in Figure 5.10c, a threshold, T_{swn} is set and all the energy values of the normalized spectrogram above this threshold are considered as part of a potential acoustic event. The detections, or contours, were used for later seismic and marine mammal detection and classification. Figure 5.10c is referred in the following sections as the binary spectrogram.

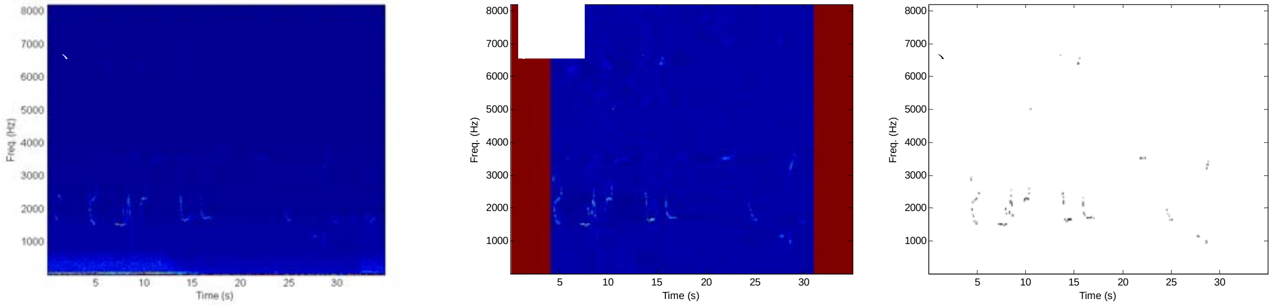

FIGURE 5.10. Events detection process. a) Original spectrogram, b) Normalized spectrogram (the 4 seconds at the beginning and the end of the spectrogram (red bands) are set to zero because of the moving average border effects) , c) Detected contours.

The normalizer window width was set to 48 time cells (3 seconds), and the notch was set to 16 time cells (1 second). This allowed for a target transient length of up to five seconds in duration at any one frequency. The power ratio threshold for the detector was set to 4, representing a Signal-to-Noise-Ratio (SNR) of 6 dB. This means the narrow-band signal strength within the five-second time window had to have at least 4 times the power of background noise for it to trigger the detector.

Ambient Noise

Two approaches were used to compute ambient background noise levels. In the first approach the average ambient level was determined at each frequency for the entire time period, including times of vocalizations and other impulsive sounds such seismic noise. In the second method, ambient noise was calculated only from times not containing vocalizations and seismic sounds. Because shipping noise was present throughout the data, it was decided to include it in the second type of ambient noise measurement.

Both approaches lead to computation of power spectral densities (PSD) for each recording file (33 minutes of data). The PSD was expressed in dB *re* 1 μPa/√Hz with frequency resolution of 4 Hz and was stored in the xml output file created by the automatic processor. The validation of the processing conversions is presented in subsection ***Processing Stream Validation***.

Seismic Levels

The seismic detector was based on the periodicity of airgun events. The detection results (*i.e.* contours) of the binary spectrogram in the 30 – 400 Hz frequency band were summed for each time step, providing a pseudo-time series. Figure 5.11a shows the resulting pseudo-time series in the case that only the first half of the file had seismic events. The autocorrelation of this time series was then computed to obtain a new series as shown in Figure 5.11b. To equalize the correlation peaks, the autocorrelation was normalized using a split window normalizer (Stergiopoulos, 2001) and we obtained the result shown in Figure 5.11c.

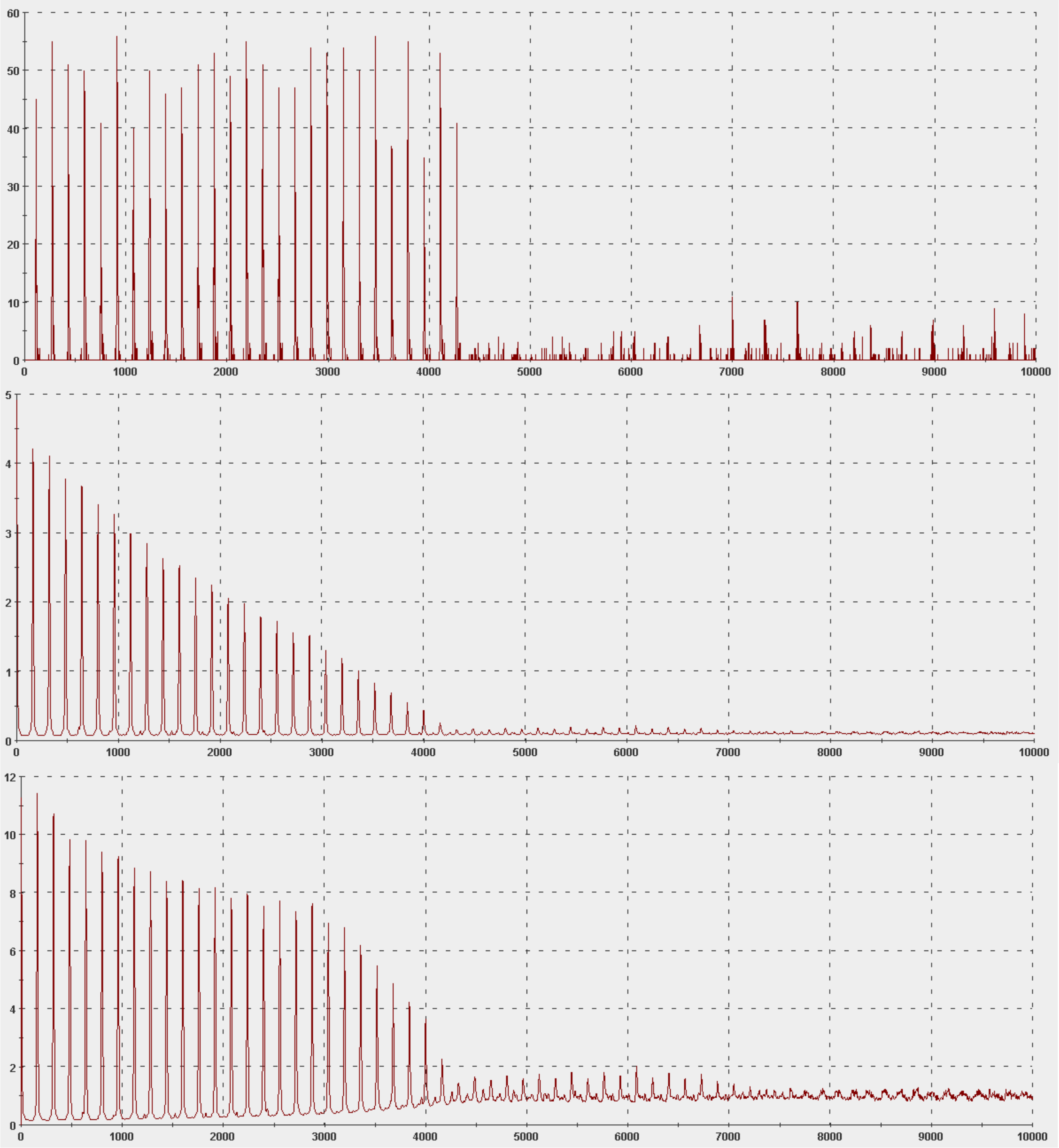

FIGURE 5.11. Seismic detection process: a) upper plot, time series of detection in the 30-400 Hz frequency band, b) autocorrelation function of the time series, c) normalized autocorrelation function of the time series.

It is apparent from in the results of Figure 5.11 that when seismic pulses were present their strong peaks reduced the mean normalized value to much less than one (notice the troughs between peaks in Figure 5.11c). However, when seismic was not present the mean value was close to one. To avoid false detections we used the following specific method to implement detection: if more than 66% of the values in the first 100 seconds of the normalized autocorrelation function were below 1, then the recording was discarded from the seismic detection process. Otherwise, if at least 10 regular peaks greater than 2 occured on the normalized autocorrelation function, then seismic was detected and the period of the airgun sounds was defined as the time between the first two peaks.

Once a period was extracted from the correlation function, it was used to locate in time each seismic event in the raw time series. We then compute the *rms* sound pressure levels using the following approach:

1. Compute cumulative energy (square pressure) for the duration of each pulse from 1 second before to 1 second after the detection. The detection time generally falls near the strongest part of the pulse;
2. Determine the interval over which the cumulative energy for each received pulse increases from 5% to 95% of the total.
3. For each pulse, compute the standard 90% root-mean-square level by dividing the cumulative square pressure over the 5% to 95% interval by the number of samples in this period, and taking the square root.
4. For each pulse, compute the sound exposure level (SEL) by time integrating the square pressure over a 2 second pulse window.

The time and sound pressure levels of each seismic event were stored in the XML output file produced by the seismic processor.

Shipping

Vessels sounds can be recognized in acoustic recordings by continuous tonal sounds at low frequencies that are produced by propulsion systems and onboard machinery (Arveson and Vendittis, 2000). The automatic ship detector looked for the narrow frequency peaks associated with these sounds.

The vessel detection process was as follows: a high-resolution spectrogram was computed using 2 s FFT's (32768 points) with 50 percent overlap. Only frequencies between 1 Hz and 1000 Hz were considered. To highlight the constant frequencies across the time, an averaged spectrum was computed for each 60 consecutive spectrogram time slices, representing 1-minute of recording. The split window normalizer described in Appendix H was applied to these average spectra to emphasize the narrow peaks. Each set of 4 normalized spectra was then analyzed using an *M out of N detector*; if on 4 consecutive normalized spectra, the same peak occured at least 3 times, then a tonal was detected.

The confidence in a shipping detection was based on the number of tonals detected at each time. If there were 1 or 2 tonals present, then the detection was *possible*. If there were 3 it was declared *probable*, and if more than four were detected it was declared *definite*. The time, confidence, frequency, signal to noise ratio and sound pressure level in dB re 1 μPa/√Hz of the detected tonals was saved in the output xml file for further validation and ships identification.

Biologics

The detection of mammal vocalizations began using the spectrogram contours method described earlier (in *Event Detection on the Spectrogram*).

The remainder of the processing was defined by an analysis of the frequency and time evolution of the contour information. We refer to aspects of this analysis as tasks (see list below). A more detailed description of the processing steps for each task is given in Appendix H.

Contours Analysis Tasks

The tasks were defined in a configuration file named contourAnalysis.xml. Each task defines identifying parameters of a particular mammal call, including:

1. Minimum, maximum and center frequencies;
2. Minimum, and maximum durations;
3. A shape parameter, one of:
   a. Moan – narrow spectral content at each time slice, but varying in frequency, and generally not as much frequency variance as an FM;
   b. FM – up or down-sweep in frequency
   c. Chatter – wide range of broadband energy;
   d. Pulse – rapid impulse type event
   e. Song – long events with several frequency swings; or
   f. Grunt – broadband event.
4. The minimum and maximum number of repetitions of the call that must be received;
5. The minimum and maximum spacing between the repetitions.
6. Whether or not the call type can occur alone. For some species we require that at least two types of call be detected. Calls that cannot occur alone are not sufficient to declare a detection of that type. Currently this is used only with walrus grunts that generate events that are very similar in duration and frequency content to bowhead calls.
7. Call probability for the species, and *a priori* probability of detecting the species. For the current study these parameters were nullified by setting their values to unity since there was not sufficient confidence in *a priori* information to justify their use here.

For each time cell and each task the numbers of detected contour points for the frequency bands were summed and the results are stored for use by the mammal estimator.

The task list was developed based on a literature review of the vocal repertoire of the marine mammals frequenting the Chukchi Sea. Five species and a total of 17 types of vocalizations were initially defined. The species of interest were beluga, bowhead, gray and humpback whales, as well as Pacific walrus. Seals were not included in the detection process but the acoustic data were later manually analyed to extract their vocalizations. The classification tasks were applied to the data, and the results were manually validated. The humpback and gray whale definitions did not produce enough valid classifications, and due to prioritization of other species we opted to exclude those classes from further automatic processing for 2007 reporting. The partial manual analysis presented later in this section does discuss some humpback and gray whale vocalizations. The automatic detector/classifier results for walrus, belugas and bowheads were sufficient for analysis and interpretation.

The validation process led to sub-categorizing a number of the bowhead and walrus call types in order to improve confidence that the calls were correctly defined. Appendix H contains a list of the call parameters used for the analysis. There were two types of signals that were especially difficult to separate into classes. The first was a distinctive call of the bowhead whale, a series of “ou-ou” pairs at a center frequency of around 200 Hz, 0.8 seconds long (see Figure 5.48). Walrus also generated a grunt that matched well to the ”ou-ou” vocalization definition. Samples of a number of walrus calls are shown in Figure 5.57.

The bowhead call characteristics were tightened to require two distinctive events in close succession and to have specific definitions for the lower frequency ”ou-ou”pair at 200 Hz and a higher frequency pair that can occur centered at 450 Hz. The walrus knock definition was tightened to require at least 2 knocks in the sequence and a maximum of 20. The walrus grunt definition was not used by itself because it overlapped the bowhead definition. This did result in walrus grunts being detected as bowheads if the walrus was not producing knocks at the same time (the bowhead definition only excluded grunts when knocks were present). No straightforward solution was found except to manually review classifications to examine accuracy and misclassification rates. Extensions to the classifier that use matched filters could improve the performance in this regard, but that was not used for the results presented in this report.

The complete set of vocalization features that constitute our *dictionary* used for the classification is contained in Appendix H.

Classification Algorithm

The first step of the classification process was to identify the boundaries of each detection. For each task the algorithm scanned through the summed contour series to determine where detection started and stopped and which frequency bins were involved in the detection. Next it determined whether the time-frequency shape of the contours detected matched the ones described in the dictionary. If one class did not match then the class was discarded. If one class did matched, this class was kept for further analysis. The match decision was based on 4 parameters: duration, center frequency, flatness and variance about the center frequency. These parameters are described in Appendix H. The rules for applying the bounds were:

1. If the date of the event was before the enable time for the task, or after it expired, then did not process. These constraints were intended to allow for *a priori* probabilities of detection, but were disabled by opening the valid times to cover the entire deployment period (in contourAnalysis.xml).
2. If the duration was less than the minimum duration, or longer than twice the maximum duration, the event was discarded.
3. If the centroid of the spectrogram frequency distribution was less than one half the specified center frequency or more than twice the specified center frequency, the event was discarded.
4. If more than half of the total contour points over the duration of the detection were outside the frequency range defined for this task, the event was discarded (as it is likely to originate from a different species).
5. Using the number of clusters of contour events, the variance of the energy, and the number of frequency cells that were part of the detection, a pattern matching was performed based on the specified shape of the mammal call (see Appendix H for details on the definitions):
    a. Moan – flatness < 5 and coverage > .05;
    b. FM – flatness < 5 and coverage > .125
    c. Chatter – flatness > 10 and coverage > .25;
    d. Pulse – flatness > 10 and coverage > .1; note that a pulsive event should also be defined as much shorter than a chatter event.
    e. Song – currently undefined.
    f. Grunt – flatness > 1 & clusters > 1.5 & coverage > .1.
6. If the event passed these constraints it was added to the tally of repetitions. If the required number of repetitions occurred within the specified time constraints, the resulting detections were summed and saved in the output XML files.
7. The last stage of detection processing occurred off line after all of the data were processed. The ‘extractDetectionResults.java’ class was run to develop the detection summaries, charts and spreadsheets used to collate the information for reporting. This class included a small amount of empirical logic that determined if the numbers and types of detections obtained in each file are significant. For each mammal class a minimum number of call events were defined that had to occur to be considered valid. At this stage, use was also made of the ‘canOccurAlone’ parameter from the vocalization definition. The significance thresholds that were applied were:
    a. Bowheads: 25 calls per file.
    b. Walrus: 2 calls per file or more, specifically of the knock type. If walrus were present, the actual number of calls was likely much higher – often in the thousands when all call types considered.

c. Beluga: 10 calls per file or more.

The second step of the classification process defined the probability that a detection belonged to a particular class. The resulting probabilities were not used presently, but the method is described in Appendix H.

Processing Stream Validation

Validation of the processing stream (not the final results) was an essential component of the overall quality assurance effort. A detailed description of validation is contained in Appendix L. The validation activities performed included:

1. Prototype Comparisons: the basic processing concepts were developed and tested initially as Matlab scripts. The resulting code and algorithm descriptions were passed to an implementation team for development in Java. After implementation the results from Java and Matlab were compared to ensure consistency.
2. Code Reviews: all software was reviewed by senior analysts to ensure correctness.
3. Data Simulation: A simulator was developed to provide synthetic instances of ambient, marine mammal vocalization, shipping and seismic noise time series. This allowed rapid validation of the performance of the processing software and exercising of the overall system.
4. Processing Stream Model: A model of the outputs from the intermediate stages of the processing stream was developed. This allowed validation of each of the intermediate processing system components to ensure correct outputs were obtained after system software revisions.
5. Manual Comparisons to Data Files: Extensive spot checking was performed to ensure that the output of the automatic processing systems matched the human analysts' interpretation of the data. All anomalies were reported to the implementation team for rectification.
6. Parameter Invariance: In many cases the absolute outputs (like SPLs) should not have changed as a function of certain processing parameters. To test this behaviour the key parameters such as FFT lengths, overlaps, and window functions were adjusted, and the absolute SPLs checked to make sure the results were invariant.

Processing Architecture

The processing architecture used for the automated detection and classification consisted of three components: the hardware, the Sun N1 Grid Engine, and the processing software. These components are described briefly below, and in detail in Appendix G.

1. Hardware: In order to process the Chukchi data in a reasonable period of time, a set of 8 quad-processor Sun Microsystems workstations with a large disk array and high-speed

network was acquired. This hardware was capable of processing the entire 5 TB data set in 60 hours, which was more than 700 times faster than real time.

2. Sun N1 Grid Engine: The processing of the 2007 Shell AMP data was accomplished with the use of a grid computing solution from Sun Microsystems named Sun Grid Engine 6.1 (also known as N1 Grid Engine or N1GE). The N1GE provided the ability to assemble a non-homogeneous network of computers into a "grid" that could be thought of as a single entity. Computing tasks or jobs were distributed across the grid in accordance with resource requirements for the job and resource availability within the grid. Use of the N1GE simplified the distribution and management of the processing load.
3. Software: The bulk analysis software was written in Java. It was architected to allow for future growth that could include real-time passive acoustic monitoring, application to other data sets, and extension of the capabilities to enable detection of other signal types.

RESULTS

Ambient Noise

The ambient noise study considered all acoustic data from both the first and second deployments. Spectrograms, decade band and broadband RMS ambient sound level plots have been created for each recorder deployment and are presented here. These results show sound level variations over the entire deployment periods. They illustrate the variability of ambient sound levels and frequency content over the open water period. Example figures of ambient level results are presented and discussed in this section. Ambient level plots for all deployment locations are presented in Appendix I.

Two methods of analysis were considered. The first method involved computing sound levels and spectra from the original (raw) data set. The second method excluded the detected transient events of biological sounds and seismic noise. With transient events excluded, the variation in ambient noise conditions due to physical processes such as weather, ice proximity and ocean sound speed profile change could be more directly analyzed. Both sets of results are included in this report.

The purpose of the ambient study was to determine the absolute noise levels present and their temporal and spatial variations. The distribution of OBH sub-arrays offshore Cape Lisburne, Point Lay, Wainwright, and Barrow provided a good coverage of the offshore region along the entire Alaskan Chukchi Sea coast. The ambient levels are relevant for evaluating potential impacts of future seismic exploration activity because they establish the acoustic baseline onto which anthropogenic sound from those operations will be superimposed.

Description of Plots

Three types of graphical presentations of ambient level data were created for each OBH deployment location: band level plots, spectrograms, and spectral level percentiles. The broadband and decade band level plots show the sound pressure levels (SPL) versus time in the frequency bands: 1 Hz - 8 kHz, 1 Hz – 10 Hz, 10 Hz – 100 Hz, 100 Hz – 1 kHz, and 1 kHz – 8 kHz. Two spectrograms plots are provided for each sensor: the first represents the total average spectral levels per recording (~ ½ hour), and the second represents the average background levels found by removing any scan time that included mammal or seismic detections. Both types of spectrograms display spectral levels between 1 Hz and 8 kHz referenced to 1 Hz frequency bins computed by averaging all data that did not contain transient events. The 5th, 25th, 50th, 75th, and 95th percentiles (sometimes referred to as quartile spectral levels) of the 33 minute spectra over the entire deployment period were also computed and plotted. This analysis approach is the same as was used with Chukchi program data collected in 2006 (Clark *et al.*, 2007), though the 2006 analysis was limited to much shorter time selections (between 1 minute and 24 hours) and the recording bandwidth was smaller so the highest frequency reported was 1 kHz. The 2007 ambient statistics presented here span the frequency range from 1 Hz to 8 kHz.

The band levels and spectral plots represent the decade bands and broadband frequency characteristics of the ambient data over the duration of each deployment. Figure 5.12 below shows as an example the entire period spectrogram and decade band levels for the Wainwright 15 first deployment location. It can be seen that the highest measured levels occurred in the 1 Hz to 10 Hz band, where spectral levels reached as high as 115 dB re μPa/Hz and median spectral levels were near 95 dB re μPa/Hz. Two result sets from analysis with and without removal of marine mammal vocalization detections and seismic sounds are shown in Figure 5.12. The top figure shows the ambient noise calculated by using the entire data set. The bottom figure is computed with mammal vocalizations and seismic events removed. The differences between the results of these two methods of computing ambient noise were minimal.

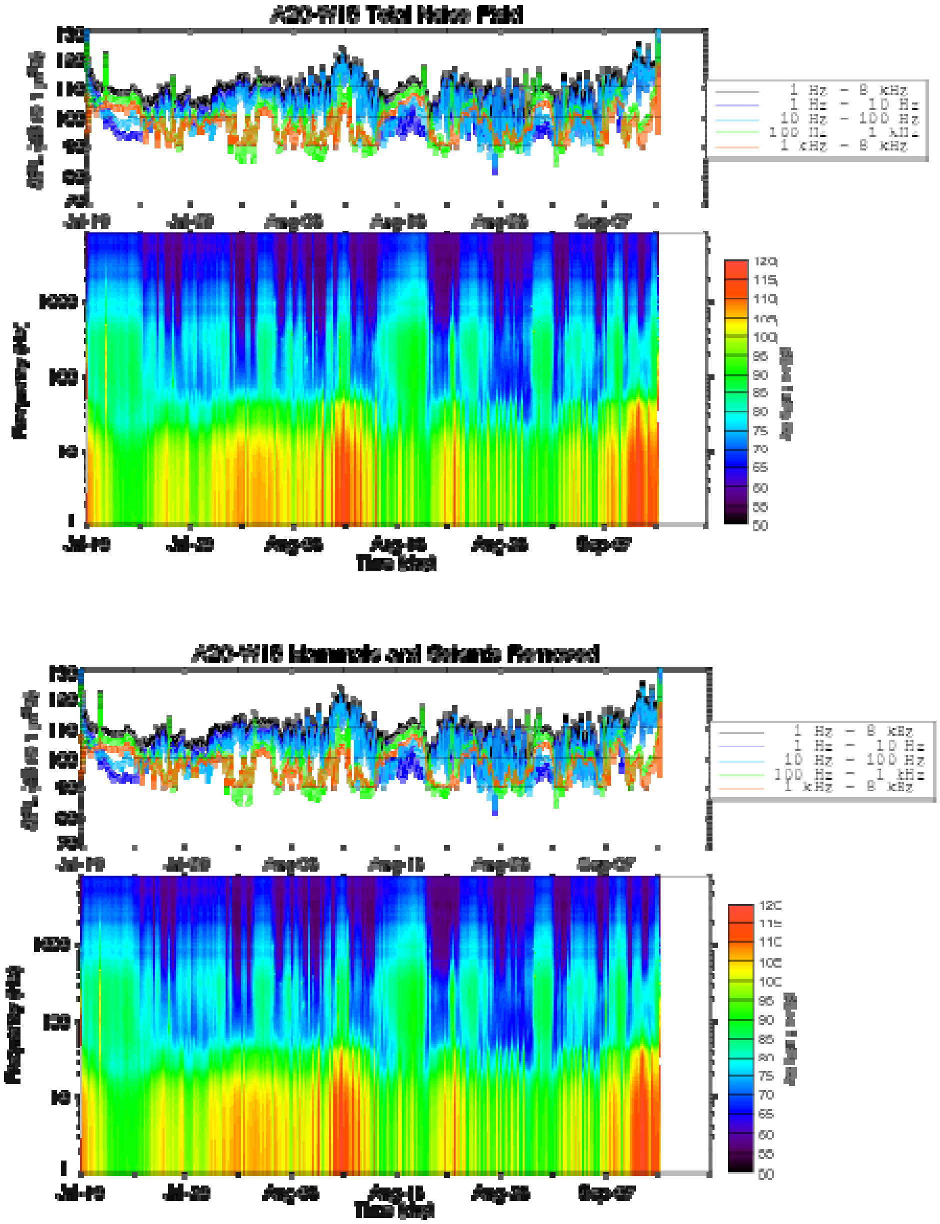

FIGURE 5.12. Decade band levels and spectrogram from first deployment of at W15 (FFTSize 4096, real samples 2048, overlap 1024, unnormalized).

Average curves were created to compare the ambient measured SPLs versus frequency to the expected results. The expected results were based on the Wenz ambient curves. The following diagram, Figure 5.13, shows the 95, 75, 50, 25, and 5 percentile curves for the first deployment of CL05. Spectral levels dropped rapidly with increasing frequency to 30 Hz, with the median levels decreasing from about 90 dB re µPa/Hz to 75 re µPa/Hz. Median spectral levels between 100 Hz and 1 kHz decreased little, from approximately 73 dB re µPa/Hz at 100 Hz to 70 dB re µPa/Hz at 1 kHz. Spectral levels dropped off above 1 kHz, to approximately 63 dB re µPa/Hz at 8 kHz. These results were comparable to those collected in the 2006 program.

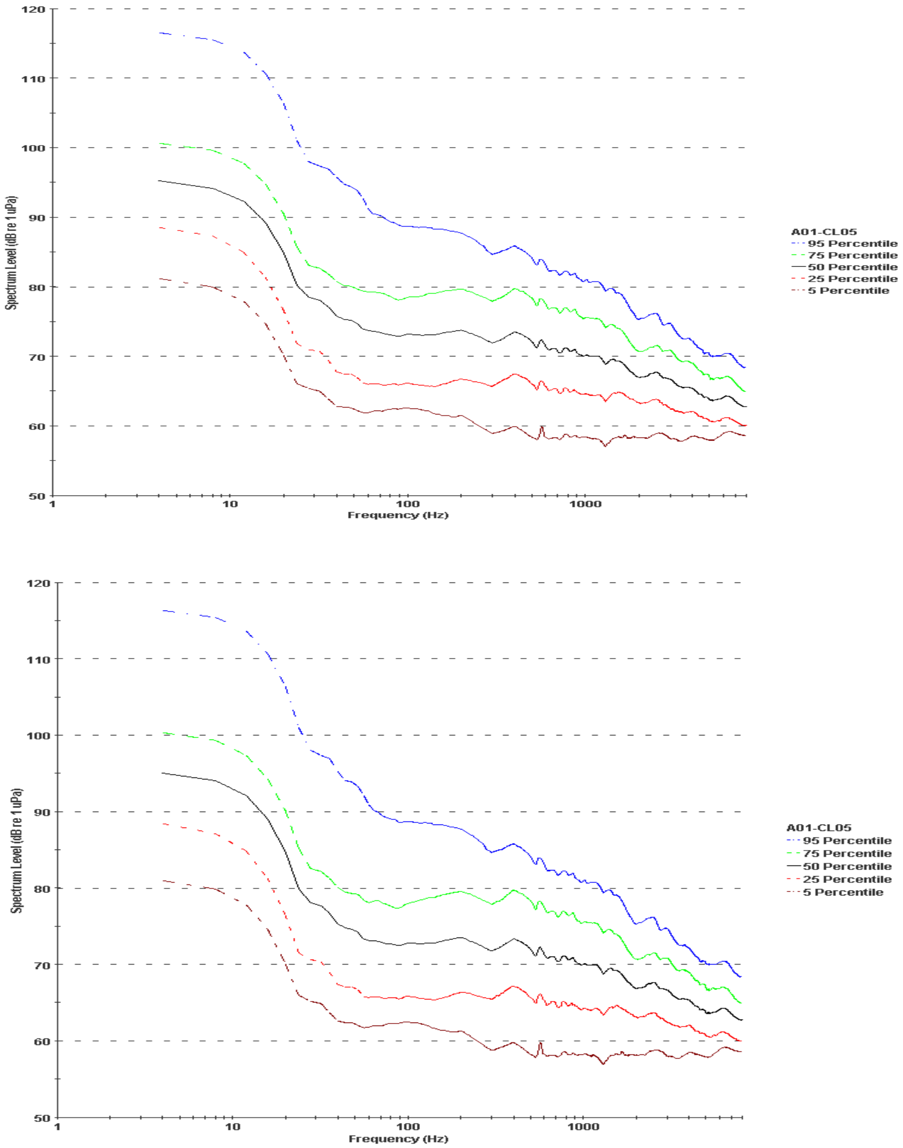

FIGURE 5.13. Percentile spectral levels (dB re µPa/Hz) at CL05. Top figure is the total ambient noise field, the bottom figure has had mammals and seismic removed. Differences are minor.

Very Low Frequency Coastal Ambient Noise Source

At various times throughout the season an intense very low frequency (less than 100 Hz) rumble was observed in the sound recordings from buoys nearest to the coast. These sounds were correlated on different sensors but not entirely with wind conditions. While levels did increase in high wind conditions, as would be expected due to noise generated by surface wave activity, there also was a noted sound level increase during a period of temperature change while wind speeds remained relatively low. Figure 5.14 and Figure 5.15 show ambient noise spectrograms for a 6-week period on the four sensors closest to shore of the Wainwright line. The noise effect described above was strongest at low frequencies as is apparent in the spectrograms. The two dates: 13 Aug and 9 Sep were especially affected by this type of noise.

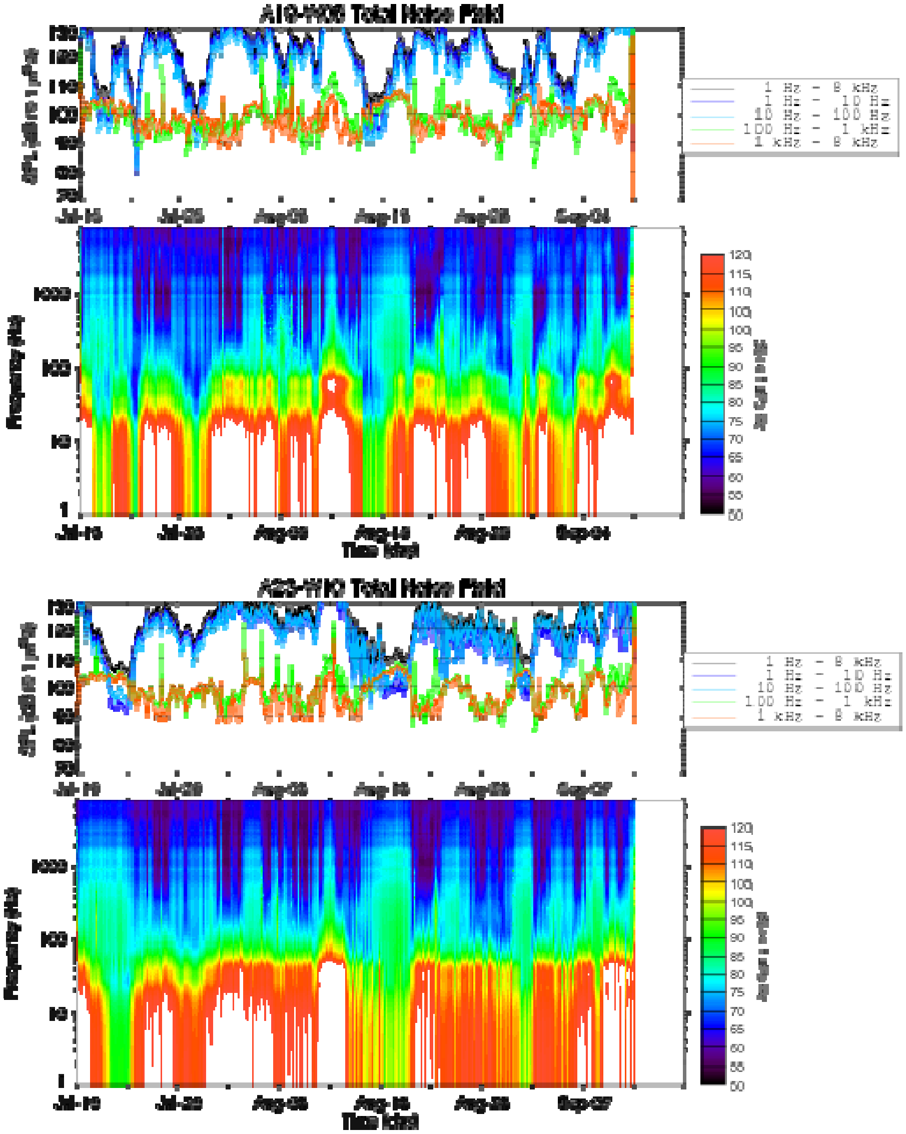

FIGURE 5.14. First deployment total ambient noise spectrograms for W5 and W10 OBH locations (FFTSize 4096, real samples 2048, overlap 1024, unnormalized).

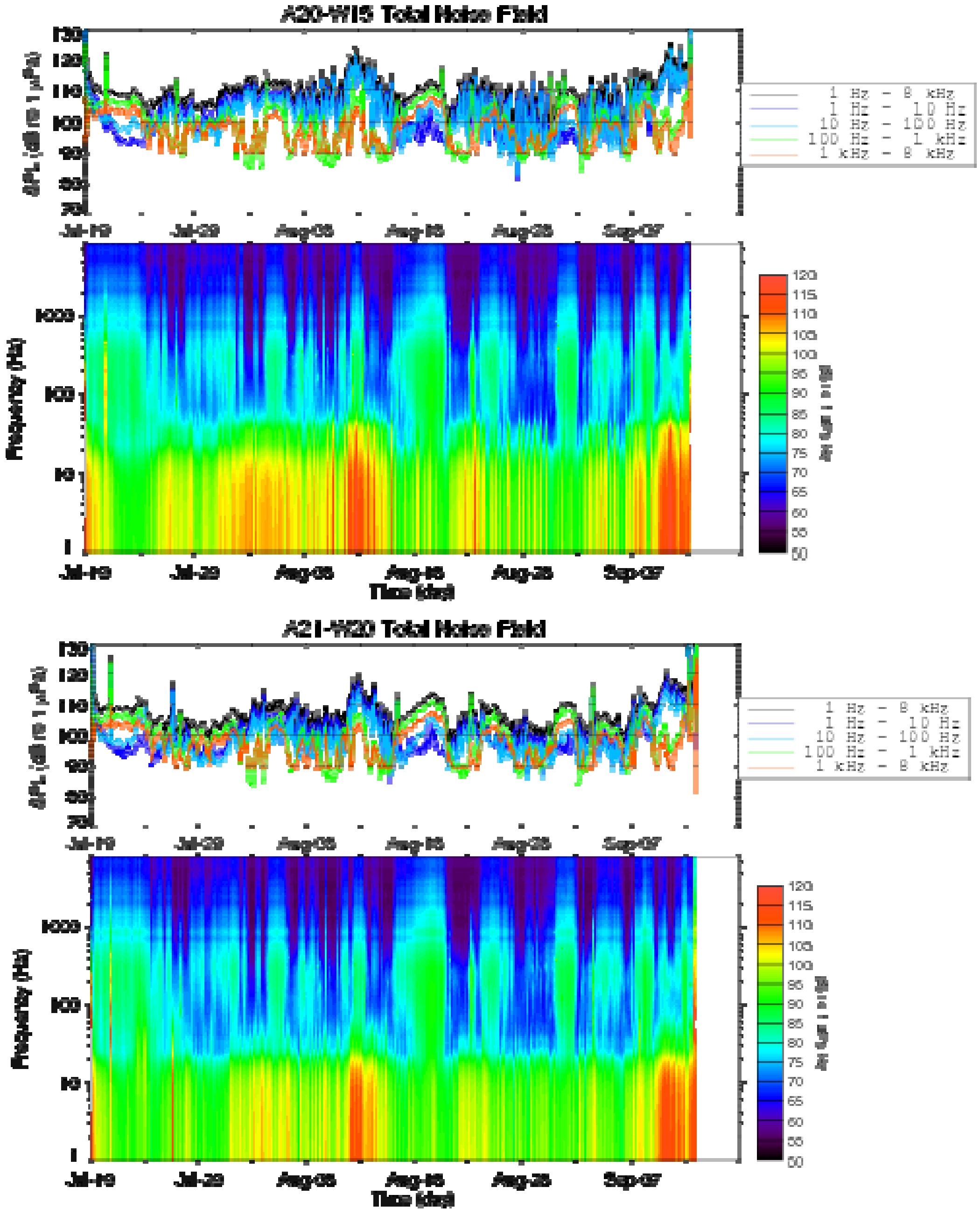

FIGURE 5.15. First deployment total ambient noise spectrograms for W15 and W20 OBH locations (FFTSize 4096, real samples 2048, overlap 1024, unnormalized).

Figure 5.16 shows a spectrogram of 2 minutes of data from 13 Aug at W05. This spectrogram was normalized to enhance data regions that varied compared to their local backgrounds. This showed a periodicity of approximately 1/6th of an Hz (1 cycle every 6 seconds).

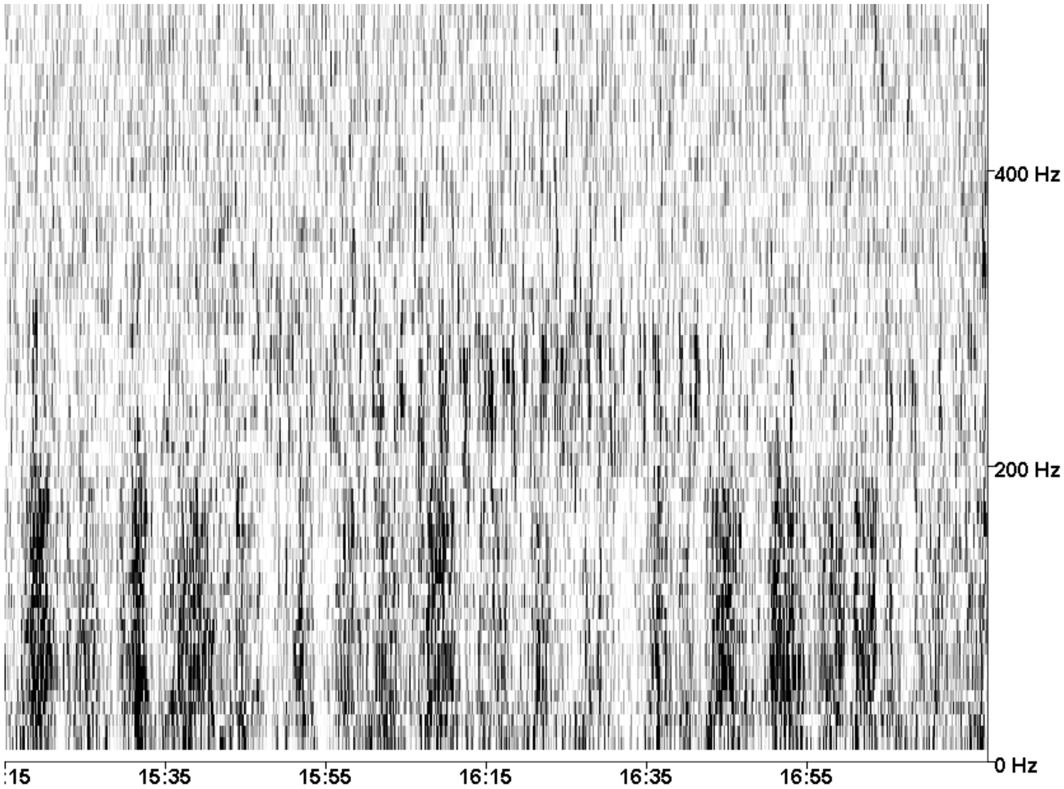

FIGURE 5.16. Normalized spectrogram of data from 12:00 AKDT, 13 Aug 2007. OBH W05, File 1A2B1062. (FFTSize 4096, real samples 1024, overlap 512, normalized)

Wind speed and temperature data were obtained from the NOAA's National Data Buoy Center monitoring stations at Prudhoe Bay and at Red Dog Dock, approximately 150 km Southwest of Point Hope (station locations shown as red triangles in Figure 5.17).

The wind speed and temperature data from the Prudhoe Bay station are shown in Figure 5.18. On 13 Aug 2007, both sites showed relatively low wind speeds of approximately 5 knots at 03:00 GMT, or 19:00 12 Aug Alaska Daylight Time (GMT minus 8 hours). They both also showed fairly substantial temperature changes with temperatures increasing to 15 – 18 Celsius (59-64° F), compared with average temperatures 5 – 8 Celsius (41-46° F). On 9 Sep, the environmental data showed average temperatures, but higher wind speeds reaching over 20 knots, and likely higher sea-states to which the noise increase on that day is attributed.

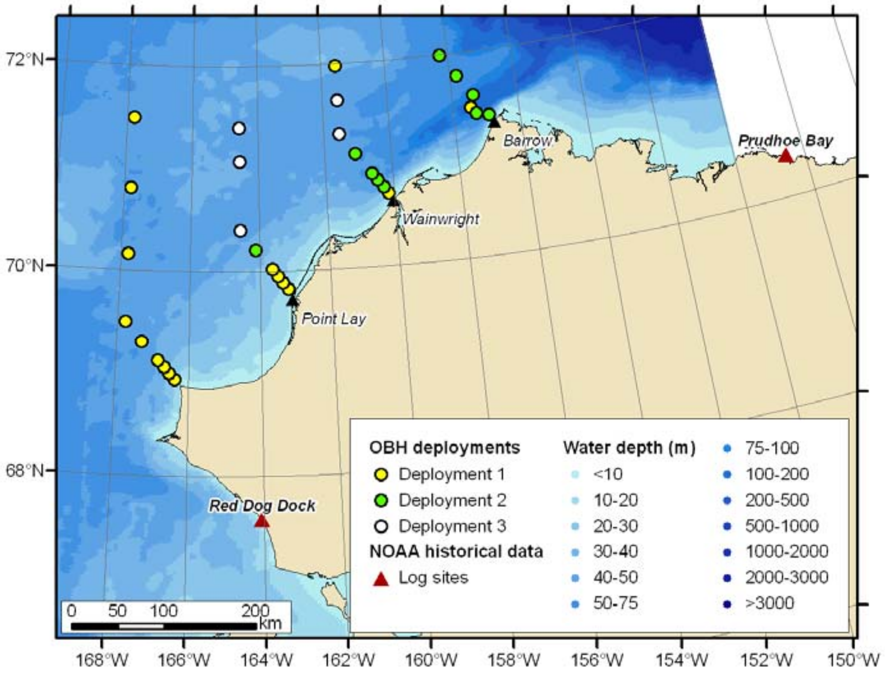

FIGURE 5.17. Locations of NOAA weather stations.

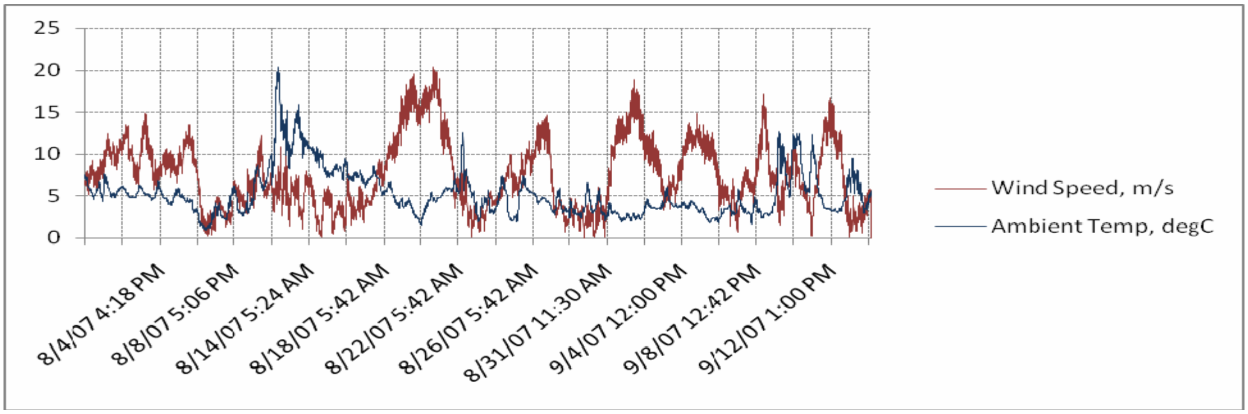

FIGURE 5.18. Wind speed and temperaturs at Prudoe Bay, Aug and Sep 2007.

Proximity of sea ice was also investigated to determine if it could influence the local levels of ambient noise. Figure 5.19 shows the ice coverage for the Chukchi, taken every Friday for the period of 13 Jul – 23 Aug. The ice reports showed that the ice edge was more than 200 km distant so probably was not a significant source of noise on the dates 13 Aug and 9 Sep.

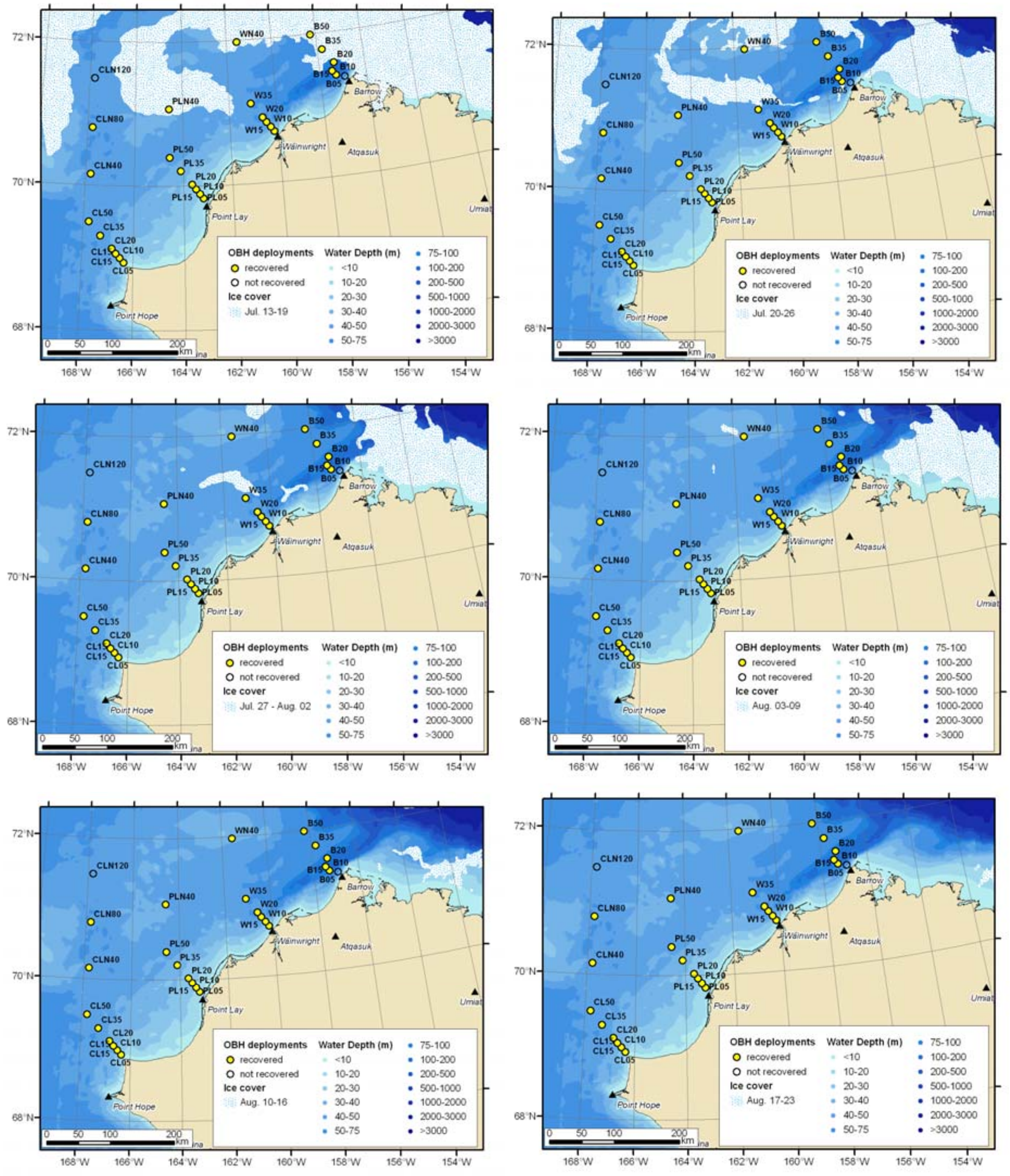

FIGURE 5.19. Chukchi ice coverage, 13 Jul - 23 Aug 2007.

Figure 5.20 shows the temperature measurements taken by the internal temperature sensors of the OBHs deployed at W05, W10 and W20 on the first deployment. There is clear correlation between these underwater temperature variations and the rise and fall of ambient noise (Figure 5.15).

On 18 – 19 Aug the water temperature measured on the OBHs' internal sensors dropped significantly, implying the presence of a layered system of warm surface waters overlying colder deeper layers. A CTD cast taken from the Gilavar in late Aug indicated a very strong 2-layer system of warm water over cold water. The temperature at the boundary between the layers appears to have varied abruptly over a vertical distance of less than 5 m. The temperature changes noted on the OBHs was likely due to mixing of the warmer surface water into the colder bottom layer following storms that mixed the layers. Because the upper layer had higher sound speed, an upper layer sound channel did not exist when layering was present. The likely reason for increased sound levels during these periods of higher bottom temperature was that water movement produced by the surface weather caused the mixing. The noise was likely a combination of weather-related noise at these times and also the resulting water movement at the bottom that caused spurious signals on the sound recordings due to water flow over the hydrophones. The latter would account for the higher levels noticed on the shallower near-shore OBHs, as water movement induced by rough weather would have decreased with increasing depth. The presence of the layering could have an additional effect – when layers were present some acoustic modes present in the lower layer would not have been as strongly coupled to near-surface sources. However, that would affect higher-frequency modes more than low frequency modes and most of the noise level variation was observed at low frequencies. Consequently the effect was most likely due to wind-driven current and weather-related turbulence that extended to the seafloor.

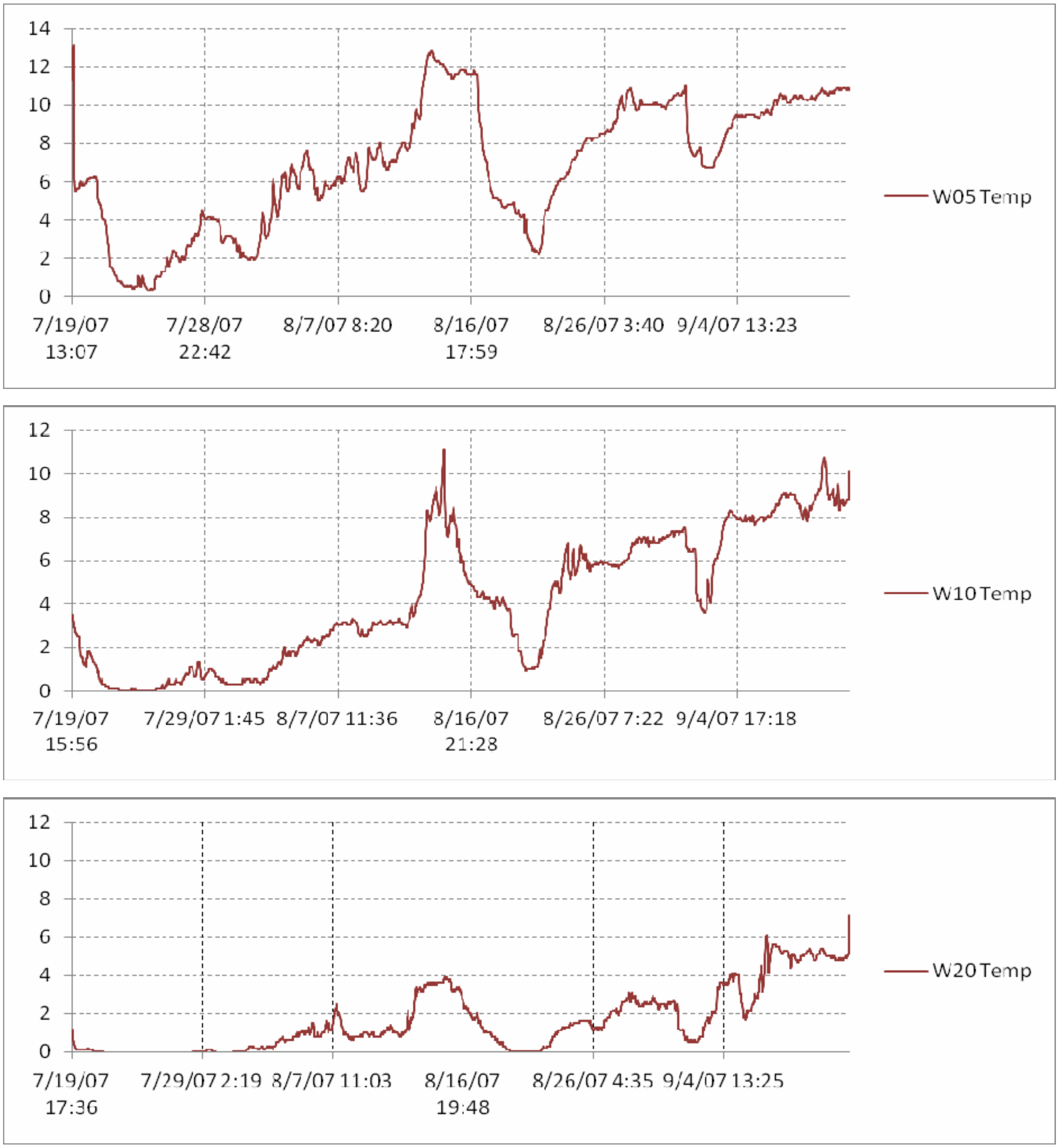

FIGURE 5.20. Temperatures at W05 (top), W10 (middle) and W20 (bottom) OBHs, first deployment.

Discussion of Ambient Results

Comparison to Wenz Curves

It can be seen by comparing the 50 percentile (mean) SPL levels versus frequency curve of CL05 to the Wenz curves, displayed below in Figure 5.21, that the shipping and ambient noise levels in the arctic were very low. Comparing the ambient mean curve to the heavy traffic noise curve of the Wenz curves it can be seen that there was very little shipping noise at CL05. The heavy traffic curve had a maximum SPL of over 90 dB. Over the same frequency range, the CL05 mean curve had a maximum of 85 dB. The mean curve of CL05 was also lower than the "Usual Traffic Noise-Deep" and "Usual Traffic Noise-Shallow." This was due to the fact that shipping traffic in the arctic regions was of relatively low entity compared to more frequented waters. The mean SPLs of the recorded ambient acoustic data showed relatively quiet conditions as compared to the Wenz curves.

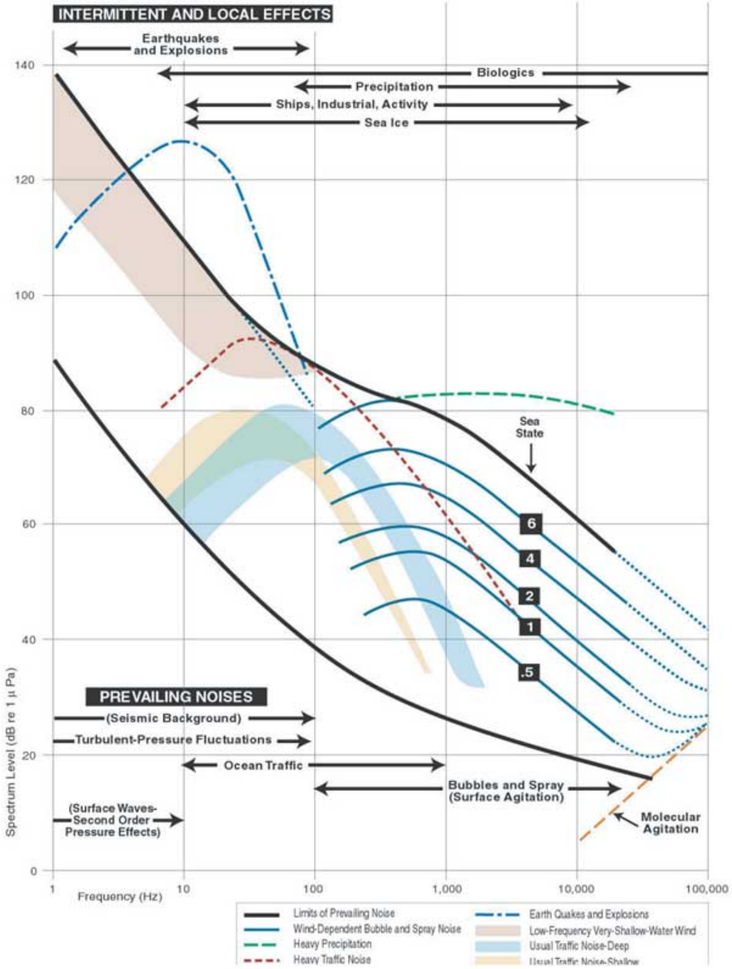

FIGURE 5.21. Wenz curves (source: http://www.dosits.org/science/ssea/2b.htm).

Seismic

The seismic detections clearly showed the SOI surveys in the Chukchi 29 Aug - 10 Sep and also 22 Oct to the end of useable data on 26 Oct. The Chukchi seismic program continued to 4 Nov. In addition another seismic survey was detected on the Barrow OBHs that started 15 Aug and appeared intermittently until 8 Oct. Three minutes of airgun activity off Point Lay were also captured around 23:10 AKDT on Aug 8. The results are presented as graphs of number of shots detected per 32-minute data file, as well as maximum RMS SPL for each hour of the day. Each graph shows the results for all of the OBHs in one line, for one deployment only.

As an example, the number of shots per file detected on the OBHs of the Point Lay line is shown in Figure 5.22 and the SPL over time is shown in Figure 5.23. An expanded view of the peak SPLs per hour for the duration of Shell's seismic survey in early Sep 2007 is shown in Figure 5.24. The results for all the stations for both the first and second deployments are presented and discussed in Appendix J. Peaks marked with a red 'x' have been manually validated to be noise.

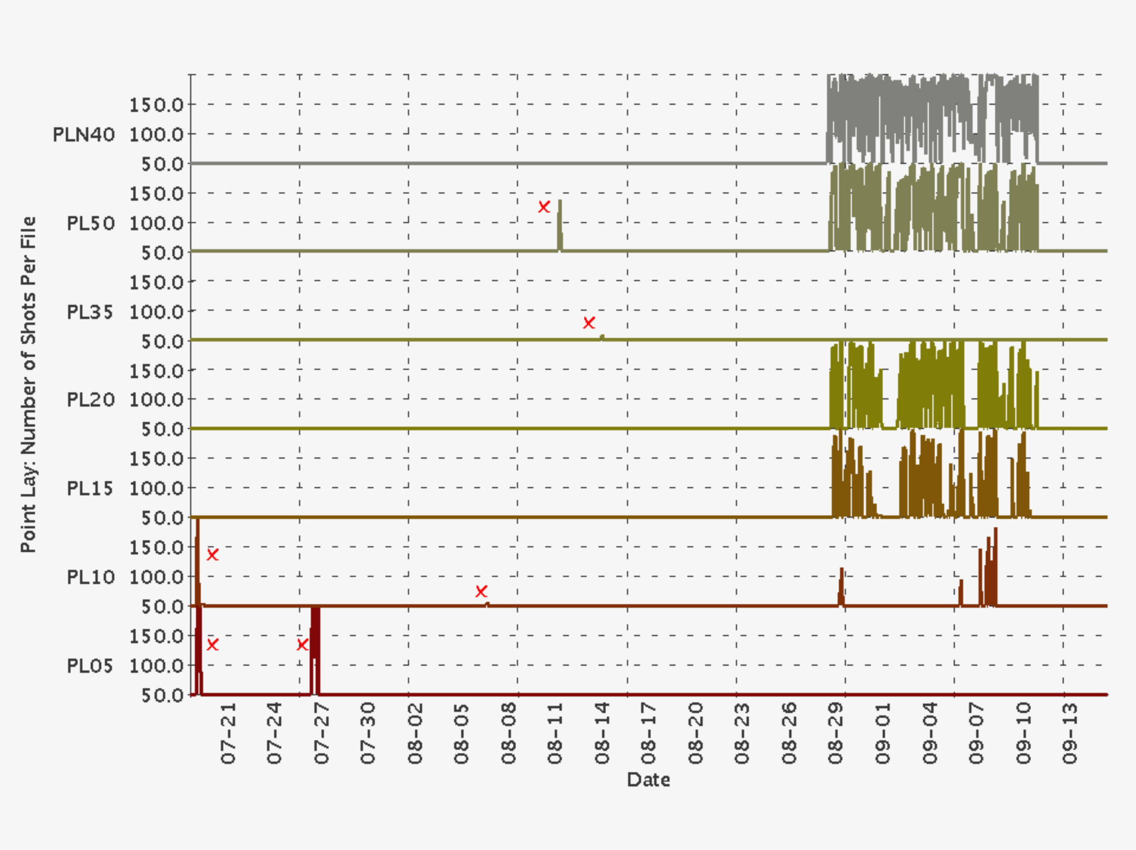

FIGURE 5.22. Seismic detections in number of shots detected per file for Point Lay from 19 Jul to 15 Sep. Peaks marked with a red 'x' have been manually validated to be noise.

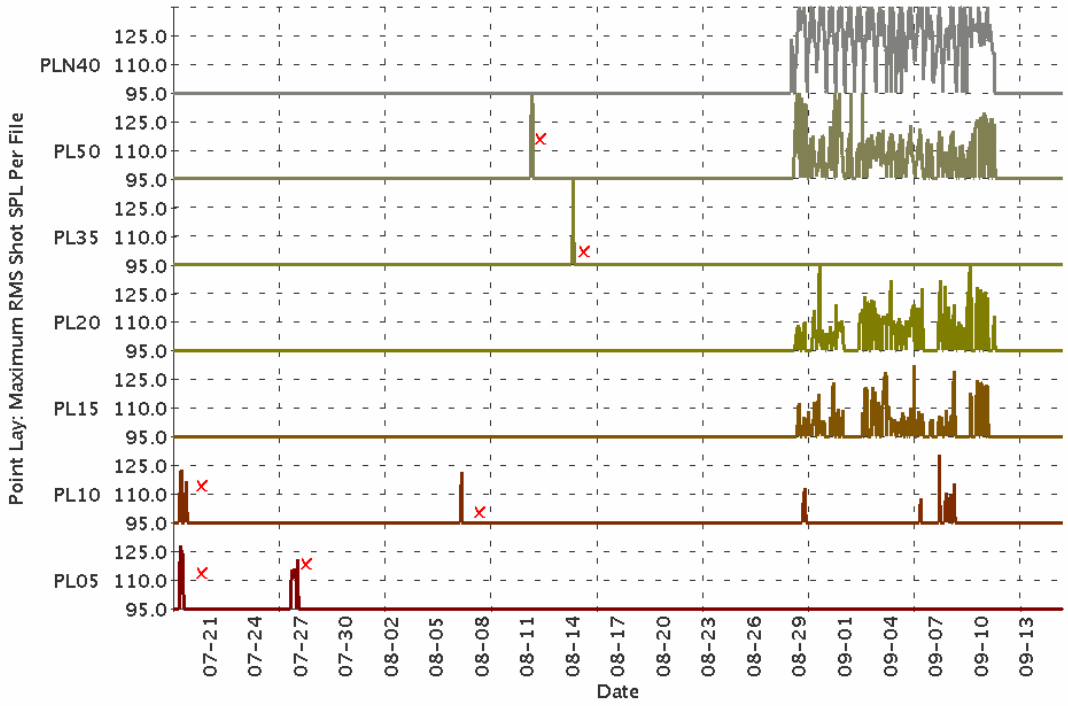

FIGURE 5.23. The peak SPL detected in 1 hour windows for the OBHs of the Point Lay line. Note that at PLN40 the received SPLs show the change in output power associated with repositioning of the array for another transect. Peaks marked with a red 'x' have been manually validated to be noise.

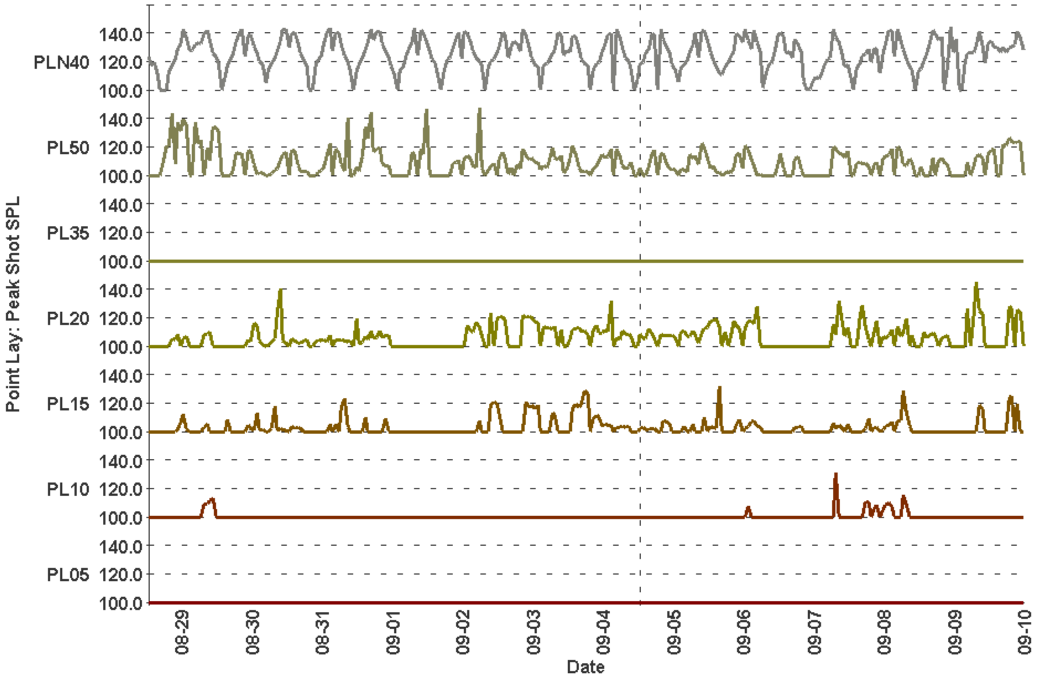

FIGURE 5.24. Expanded view of the seismic SPL values (maximum RMS in each hour), for the Point Lay line, 28 Aug to 10 Sep 2007. PL35 was not operational.

SOI Seismic Surveys

Between 29 Aug and 11 Sep, significant seismic survey related sounds were recorded on stations PL10, PL15, PL20, PL50, PLN40, W05, W10, W15, W20, W35, WN40, CLN40 and CLN80. The survey was not detected on PL35 because the recorder redeployed there on Aug 26 suffered a hardware failure. During that time the SPLs for all stations except PLN40 were generally below 115 dB SPL re 1µPa (RMS). The SPL over time on PLN40 showed a clear increasing and decreasing pattern which most likely correlated with the progress of the survey vessel closer and farther from the OBH. There was a marked drop in sound level of up to 20 dB at the end of each line as the full array switched to mitigation gun only during line changes. Average SPLs during the survey ranged from 100 to 137.4 dB SPL re 1µPa (RMS). Individual shots often reached 142 dB SPL (RMS) re 1µPa, and on two occasions exceeded 144 dB SPL re 1µPa (RMS).

During the second survey period of Oct 20 to Oct 26, the survey was detected at W35R, W50R, B35R and B50R. The SPL at W50R showed the saw tooth pattern of the first survey period at PLN40. Over a 32-minute file, average shot SPLs were as high as 132 dB re 1 µPa (RMS), and individual shots typically peaked at 138 dB SPL re 1 µPa (RMS).

Other Seismic Detections

Distant Seismic Survey, 17 Aug – 8 Oct

The OBHs of the Barrow line detected a distant seismic survey intermittently throughout the period of 17 Aug to 8 Oct. It is not known if the survey became undetectable at times during this period due to ambient noise, propagation conditions, or simply due to thresholds in the automatic detection system. For example, for Aug 17-18, manual verification showed that the survey became visible above the noise floor in a spectrogram around 00:39 AKDT Aug 17 and audible a few hours later. The survey continued at a consistent repetition rate of 21 or 22 seconds until 04:22:25 AKDT Aug 18, when it abruptly stopped. The ambient noise during this time period was unusually low, so the weak received pulses were clearly recorded even though shot SPLs rarely reached 100 dB SPL RMS re 1µPa. A spectrogram of a typical pulse is shown in Figure 5.25. The received frequency content is mostly below 60Hz and appears to consist of only one mode, which supports the assumption that the source is quite distant as higher order modes with more bottom interactions were stripped off.

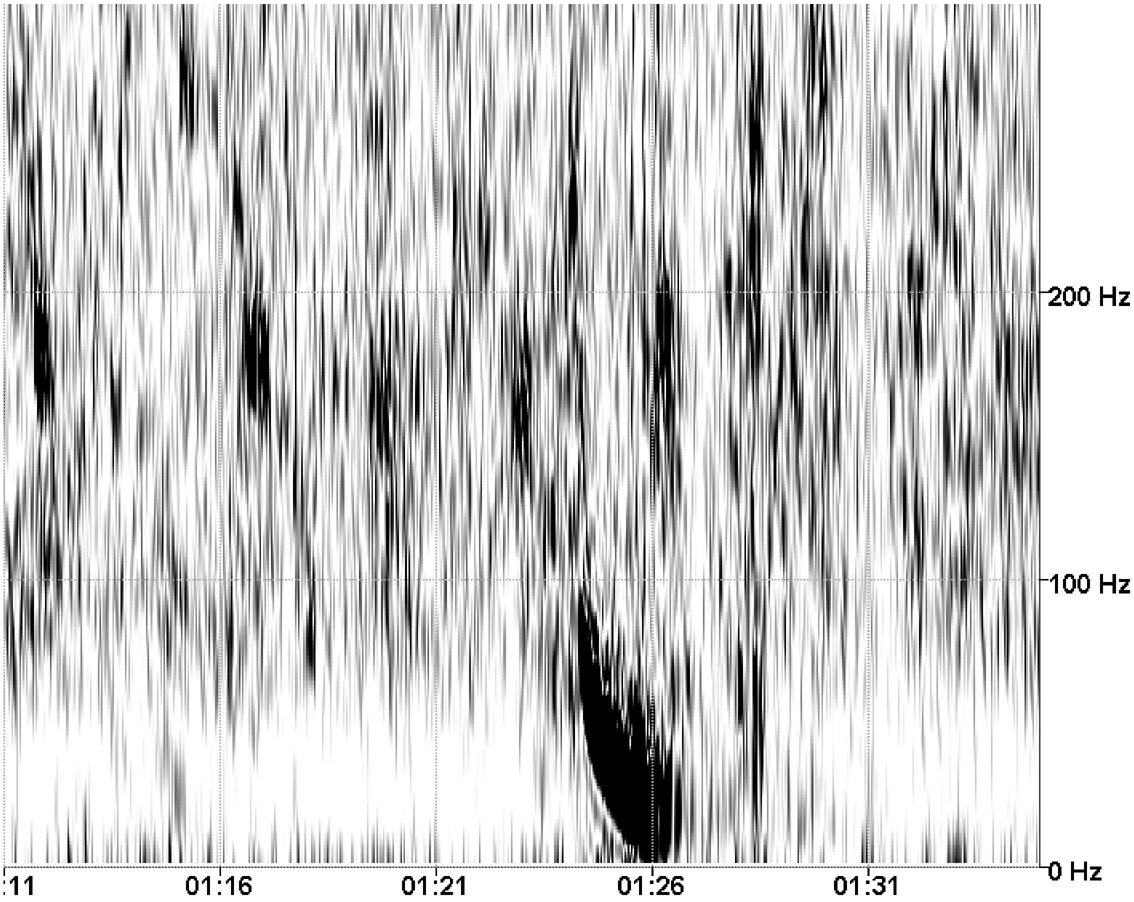

FIGURE 5.25. A single pulse of a distant seismic survey recorded at B50 on Aug 17 2007. (FFTSize 16384, real samples 1024, overlap 768, normalized)

At later times when the distant survey was detected, such as Oct 1 and 6, the pulse signature was shorter with more high frequency content, as shown in Figure 5.26, although the repetition rate remained the same at approximately 20-24s. During early to mid-Sep, both the distant unknown survey and the SOI survey were often detected simultaneously. The automatic system only detected the stronger seismic pulses, but manual verification showed two distinct repetition rates.

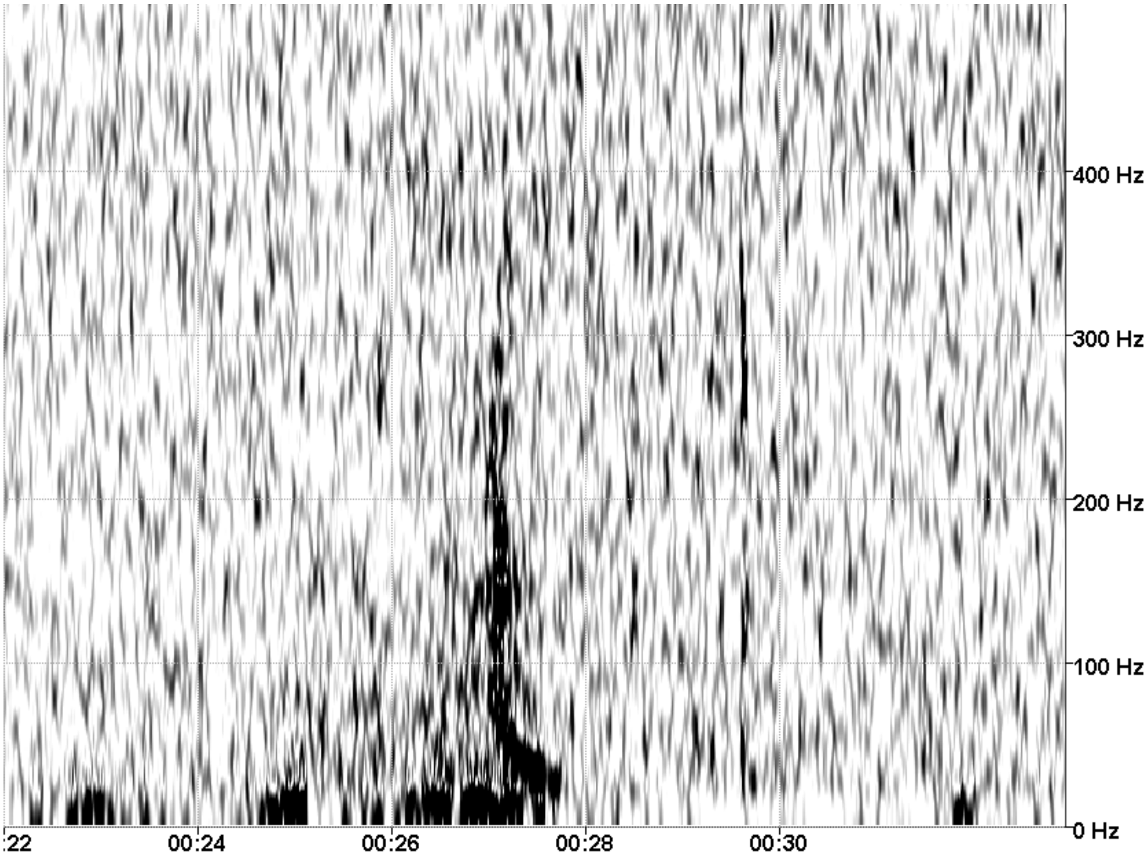

FIGURE 5.26. A single pulse recorded at B50R on Oct 5, 2007. (FFTSize 16384, real samples 1024, overlap 768, normalized)

Three Minute Seismic Event, 8 Aug[h]

On 8 Aug between 23:08 and 23:11 AKDT, a 3-minute series of airgun shots were recorded on PL15, PL20, PL35, and PL50. Since the sounds were not recorded over a very large area, it is assumed that the source level was relatively low, indicating a small volume airgun or airgun array. The repetition rate was 6.7 seconds. A spectrogram of one pulse is shown in Figure 5.27. Because the event was of such short duration, it is not reported in the summary charts in Appendix J.

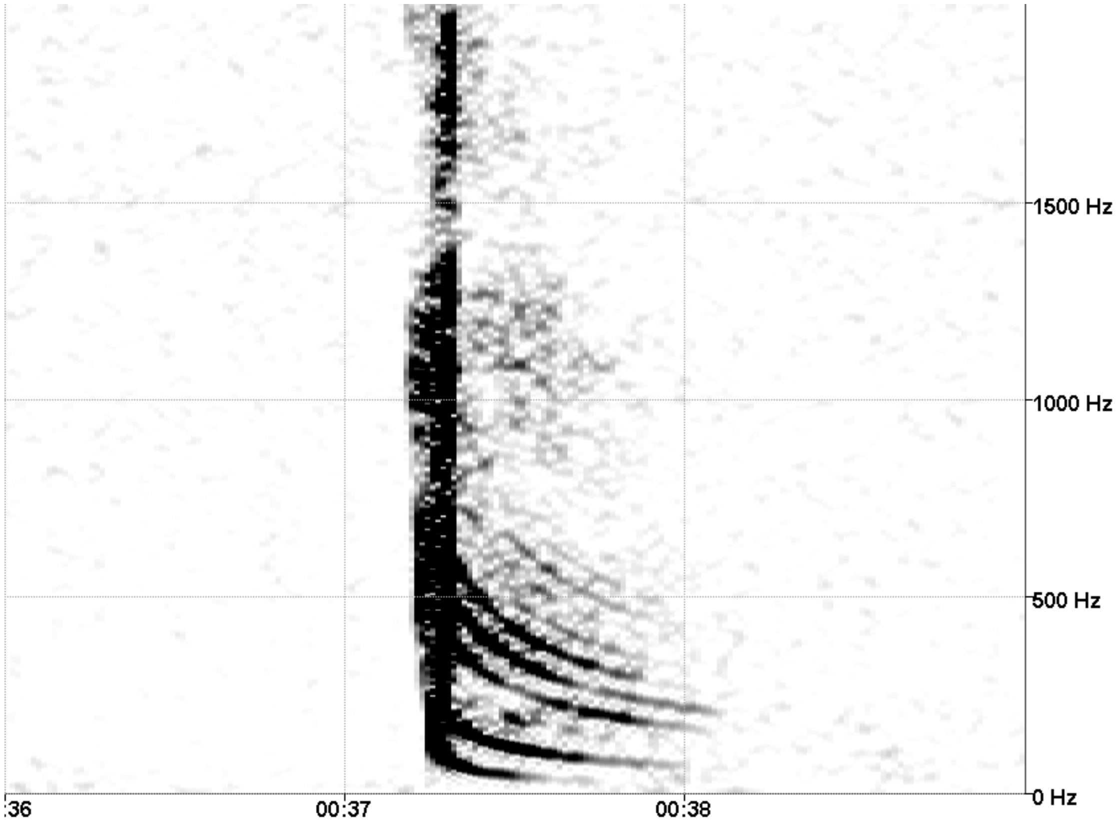

FIGURE 5.27. A pulse received on 8 Aug at PL35 (FFTSize 16384, real samples 1024, overlap 768, normalized).

To estimate the position of the unknown source, six consecutive pulses with the best SNR were identified and selected from all four data sets, and their RMS SPL was computed and averaged at each station. For each location a curve of source level (SL) versus range required to create the actual received level (RL) was generated using the standard equation of $RL = SL - 20*\log10(R) - \alpha R$. The coefficient of absorption α was taken to be approximately 0.0004 dB/m based on the results of SSV work in the Chukchi Sea during 2007. An iterative search was then performed by varying the assumed SL and plotting circles at the resulting source range from each recorder station, whose intersection would define the source location. The best intersection of the circles was obtained by selecting a SL of 210 dB re 1µPa. The uncertainty associated with this location estimate is significant, with a feasibility region possibly larger than 5 km (3 nmi) across, although this is hard to specify quantitatively.

Based on the intersection of range circles the unknown pulses could have originated either NE or SW of the recorder locations. Figure 5.28 shows the two possible locations of the event in relation to the Gilavar which was in the vicinity of PLN40. There is no indication on record that the Gilavar's airguns would have been active at that time, and a careful analysis of PLN40's data did not show any trace of the seismic events. As it is impossible to formulate a scenario in which sound originating from the Gilavar could be detected on PL35 and PL20, but not on PLN40, it can be stated with confidence that the vessel in question was not the source of these pulses.

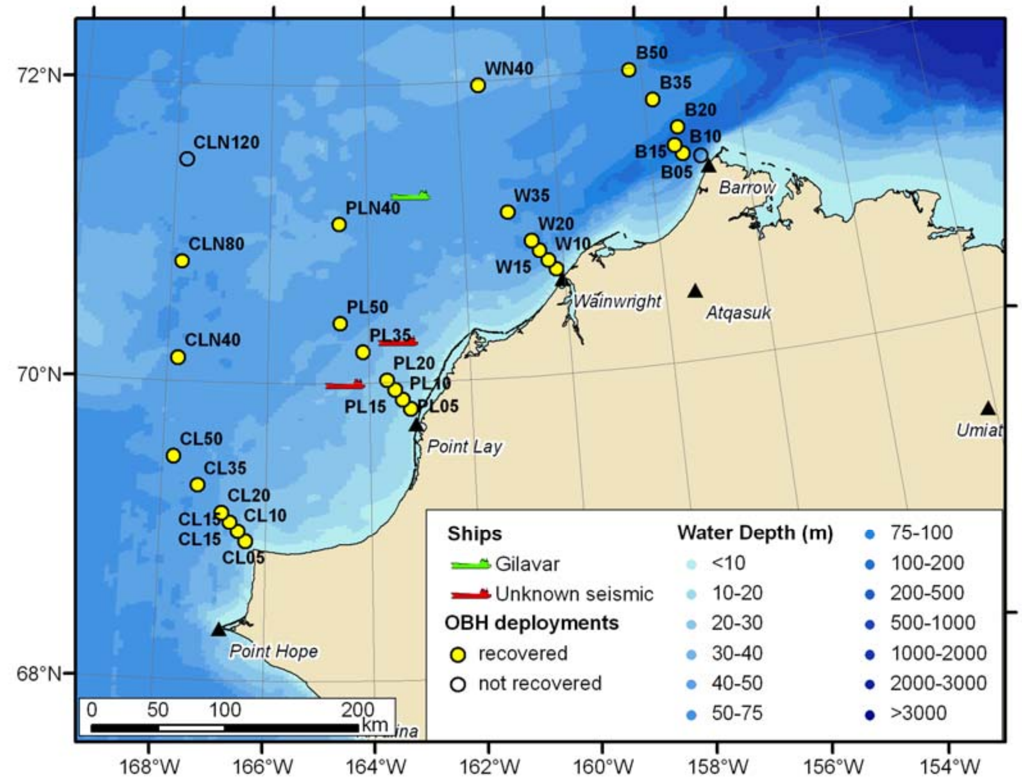

FIGURE 5.28. Location of seismic source and Gilavar, 8 Aug 2007.

False Detections

The remaining detections shown in the plots in Appendix J have been manually verified as false positives. Where false positives were detected, typically the maximum RMS SPL was high while the number of detections was low and there was no correlation between detections on nearby OBHs. Often these high SPL false detections were caused by anomalous sounds that could be due to animals brushing past the recorder, or by high level low frequency ambient sound as discussed earlier in this section under the heading of ***Very Low Frequency Coastal Ambient Noise Source***.

Spectral Content of Seismic Pulses

Figure 5.29 presents the spectral content of a high level seismic event received at PLN40, with a broadband SPL of approximately 141 dB. A comparison of these data with the 95th percentile ambient SPLs in Figure 5.13 shows that at this range the seismic events exceed ambient up to approximately 1000 Hz. Figure 5.30 presents the spectral plot of a seismic event received at a much longer range, with a SPL of 114.5 dB. In this case the event exceeds the 95th percentile ambient levels only up to a frequency of approximately 200 Hz.

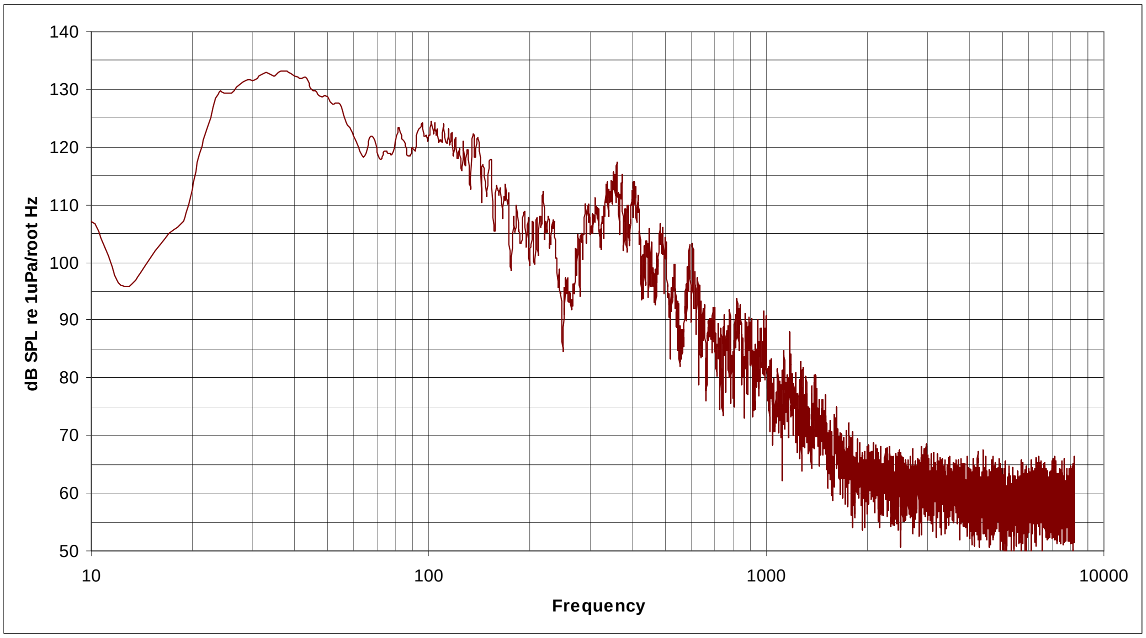

FIGURE 5.29. Spectral plot of a 141 dB broadband SPL seismic event, PLN40.

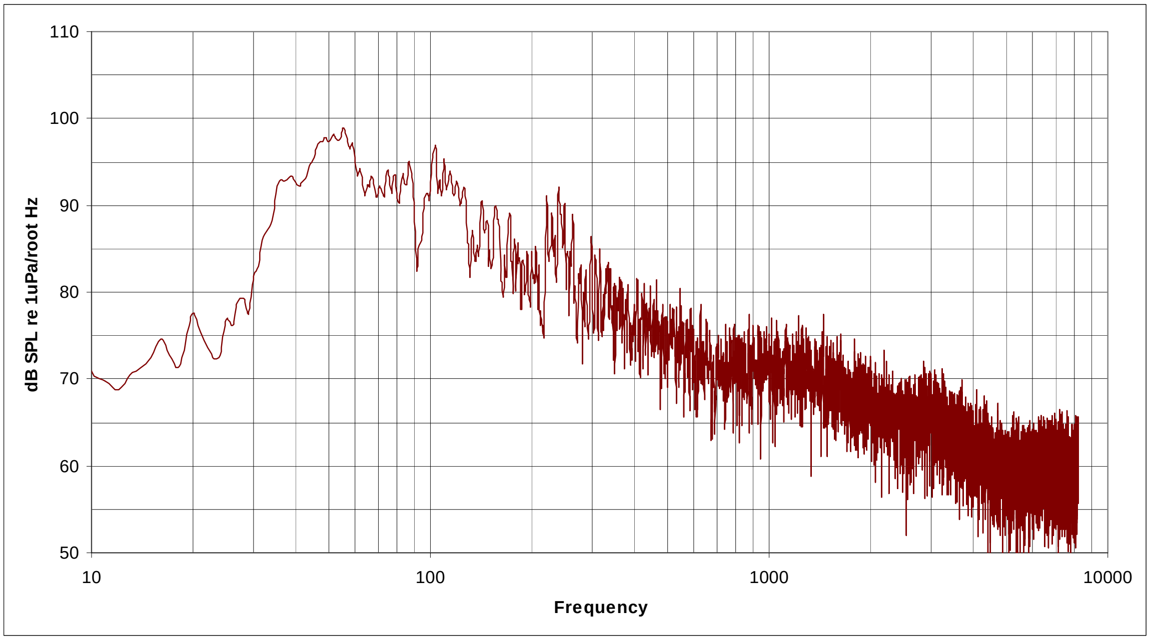

FIGURE 5.30. A 114.5 dB SPL RMS shot that occurred at approx 14:27 AKDT on 1 Sep 2007 on PLN40.

Shipping

The purpose of the shipping analysis was to provide information on the intensity of the noise emitted by the vessels associated with the seismic activities as well as any other shipping that may be detected. This section provides a detailed analysis of shipping detections for the Cape Lisburne series of OBHs, as well as some of the more interesting contacts detected near shore at Barrow. The remainder of the information is contained in Appendix K.

Cape Lisburne First Deployment

The Cape Lisburne line of the OBH net array was the first to be deployed on 17 – 18 Jul 2007. It was hoped that this line would be in place in time to capture information about the location of belugas immediately following the early summer hunt.

Figure 5.31 shows the number of tonals detected for all of the Cape Lisburne OBHs in the first deployment. The number of tonals is a metric that correlates to the amount and proximity of shipping to the OBH. To interpret these results it is necessary to account first for known shipping. Table 5.6 shows the times when the Shell vessels were within 10 nmi (19 km) of each OBH.

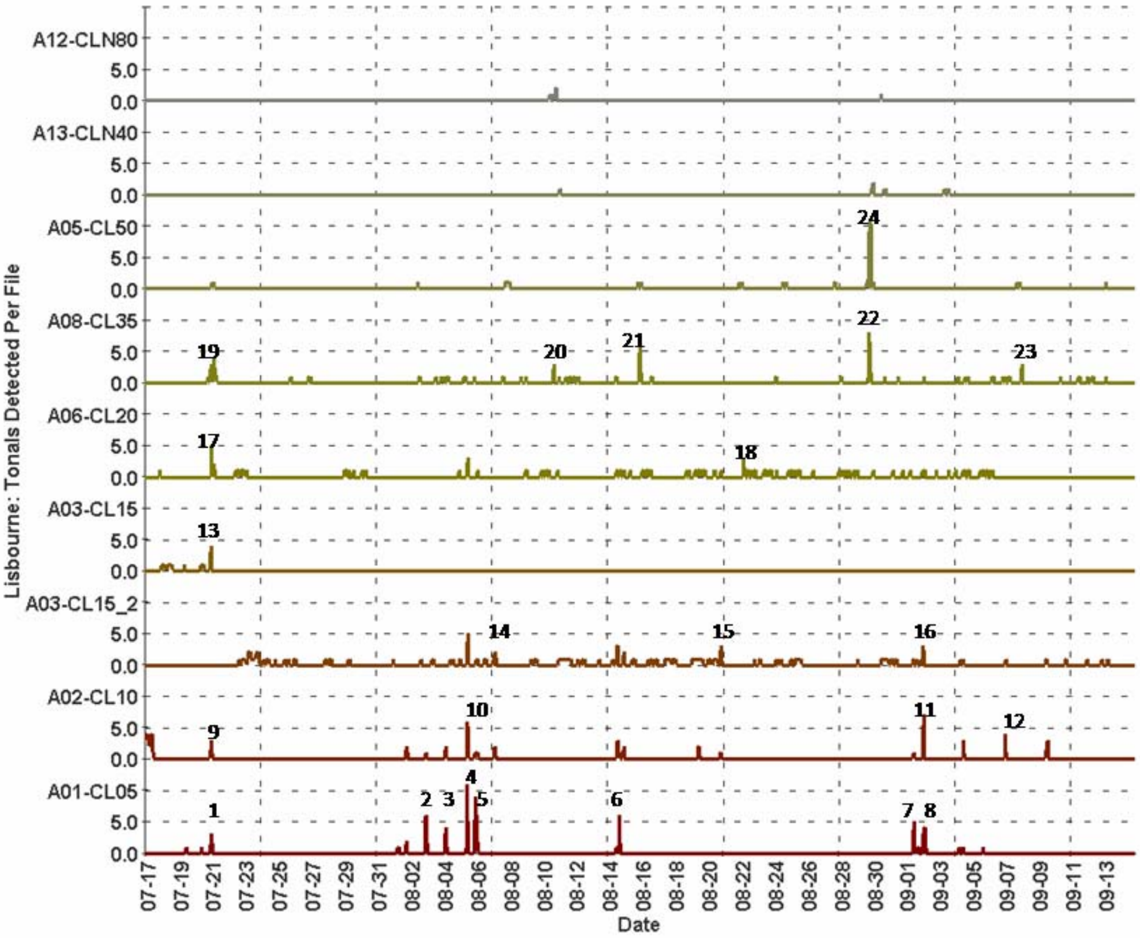

FIGURE 5.31. Number of tonals detected, per file, at the Cape Lisburne line, first deployment. The numbers on the figure are keys to Table 5.7.

TABLE 5.6. Shell vessels that passed within 10 nmi (18.5 km) of the OBHs.

OBHID	Ship	Entered 10 nm Time	Exit 10 nm Time
A01-CL05	Norseman	7/17/2007 9:00	7/17/2007 13:00
A01-CL05	Norseman	7/21/2007 23:00	7/22/2007 0:00
A02-CL10	Norseman	7/17/2007 10:00	7/17/2007 15:00
A02-CL10	Norseman	7/21/2007 21:00	7/22/2007 1:00
A03-CL15	Norseman	7/17/2007 10:00	7/17/2007 15:00
A03-CL15	Norseman	7/21/2007 21:00	7/21/2007 22:00
A05-CL50	American Islander	8/29/2007 18:00	8/29/2007 20:00
A05-CL50	Norseman	7/17/2007 17:00	7/17/2007 19:00
A05-CL50	Norseman	8/10/2007 17:00	8/10/2007 19:00
A05-CL50	Norseman	8/15/2007 17:00	8/15/2007 20:00
A05-CL50	Norseman	8/15/2007 22:00	8/16/2007 1:00
A06-CL20	Norseman	7/17/2007 12:00	7/17/2007 16:00
A06-CL20	Norseman	7/21/2007 21:00	7/22/2007 0:00
A08-CL35	AmericanIslander	8/29/2007 17:00	8/29/2007 19:00
A08-CL35	GulfProvider	7/21/2007 4:00	7/21/2007 6:00
A08-CL35	Norseman	7/17/2007 15:00	7/17/2007 18:00
A08-CL35	Norseman	8/10/2007 15:00	8/10/2007 17:00
A08-CL35	Norseman	8/15/2007 19:00	8/15/2007 23:00
A10-PL15	Norseman	7/19/2007 0:00	7/19/2007 4:00

The known shipping from Shell activities accounted for a significant proportion of the tonal peaks in Figure 5.31, but there was clearly evidence of other shipping present. Some vessel activities that are known to have occurred, such as coast guard vessel and cruise ship presence, accounted for part of the additional detections. Analyses of the main detections for the Cape Lisburne line are shown in Table 5.7. There were a number of detections of larger diesels, which would imply larger supply vessels or seismic vessels not accounted for in our tables. Table 5.7 references a number of interesting spectrograms found in the Cape Lisburne data, which are shown after the table (Figure 5.32 to Figure 5.36).

TABLE 5.7. Detections of vessels, Cape Lisburne, first deployment.

ID	OBHID	Time	File	Number of Tonals	Peak SPL	Notes
1	A01-CL05	22:00, 20-Jul-07	6DCD0173	4	83 dB @ 442	Diesel knock and rotating machinery 442.
2	A01-CL05	22:20, 2-Aug-07	6DCD0728/9	6	88 @ 164.5	Heavy sounding traffic, rotating machinery, lots of LF rumble; CPA between files. Shown in **Error! Reference source not found.**.
3	A01-CL05	03:30 4-Aug-07	6DCD0780	4	110 @ 69 Hz	Very nice CPA pattern of Lloyds Mirror Interference. See **Error! Reference source not found.**.
4	A01-CL05	10:00 5-Aug-07	6DCD0835	11	109@162.5	Lots of energy ~160-180; Diesel CPAs at mid file, but not as close as 780.
5	A01-CL05	22:20, 5-Aug-07	6DCD0857	9	91 @ 411 Hz & 91 @ 85 Hz	Slow sounding diesel; lots of broadband in the 100 – 300 Hz range. See **Error! Reference source not found.**.
6	A01-CL05	15:50 14-Aug-07	6DCD1229	6	100.5 @ 40.5 Hz	Small diesel CPAs buoy CL05. Lots of BB. Single tonal value may not be representative of total noise.
7	A01-CL05	10:50 1-Sep-07	6DCD1989	5	107.5 @ 377 Hz	Loud rotating machinery at 377, minimal low freq content. Distant CPA
8	A01-CL05	01:00 2-Sep-07	6DCD2014	4	78 dB @118	Distant diesel / rotating machinery. Also distant walrus activity.; Some lines near 540 Hz
9	A02-CL10	22:00 20-Jul-07	71900173	3	85 dB @ 442 Hz	Same contact as ID 1, CPA around 22:20. See **Error! Reference source not found.**.
10	A02-CL10	02:40 7-Aug-07	71900907	2	86 dB @ 350 Hz	Steady tonal at 350, no distinct diesel sounds, no CPA.
11	A02-CL10	00:30 2-Sep-07	71902013	7	107 dB @ 60 Hz	Strong 60 Hz and harmonics, steady source, not much knocking. CPAs early in file. 550 Hz lines present. Same contact as #8.
12	A02-CL10	10:20 4-Sep-07	71902115	3	96 dB @ 260.5 Hz	Lots of broadband wash; either boat or aerial.
13	A03-CL15	22:00 20-Jul-07	38F60173	4	109 dB @ 43 Hz; 100 dB @ 444 Hz	Same contact as ID1 and ID9.

14	A03-CL15B	12:10 14-Aug-07	38F61221	3	96 dB @ 363 Hz	Clear blade rate and rotating machinery @ 363
15	A03-CL15B	18:50 20-Aug-07	38F81489	4	110 dB @ 60 Hz	Extremely rapid CPA, 540 Hz pairs are present. Very similar to IDs 8 and 11. No knock or blade.
16	A03-CL15B	00:00 3-Sep-07	38F62011	3	77 dB @ 541 Hz	Same contact as 8, 11, and 15.
17	A06-CL20	22:30 20-Jul-07	8E9E0173/4	5	84 dB @ 436 Hz	Same contact as ID1 and ID9; CPA at 22:20, Peak freq at 439.2 Inbound, and 435.5 Outbound. Doppler speed of 7.35 knots; Note a dual source and change in frequency as shown in the frequency zoomed image,
18	A06-CL20	03:29 22-Aug-07	8E9E1549	3	84 dB @ 109 Hz	CPA at ~03:55. Lots of broadband in100-300 Hz, similar to ID 5. No diesel knock.
19	A08-CL35	21:48 20-Jul-07	527D0172	3	75 dB @ 43 Hz	Weak contact on same contact as 1, 9, 13, and 17.
20	A08-CL35	16:00 10-Aug-07	527D1055	3	86 dB @ 75 Hz	Norseman. Strong first and second harmonics of 50 Hz – European electrics on Norseman? Lots of low rumble and slow knock of a large diesel plant. See **Error! Reference source not found.**.
21	A08-CL35	21:30 15-Aug-07	527D1277	6	85 dB @ 64.5Hz	Strong first and second harmonics of 50 Hz. Correlates with Norseman
22	A08-CL35	17:35 29-Aug-07	527D1866	8	94 dB @ 103	American Islander? Clear rotating machinery, heavy engine plant; no knock
23	A08-CL35	23:25 7-Sep-07	527D2259	3	76 dB @ 206.5 H	Distant CPA at beginning of file. Lots of flow and contact noise in this file.
24	A05-CL50	18:45 29-Aug-07	5bE11875	11	87 dB @ 430 Hz	Same contact as ID 22. High freq rotating machinery. Probable American Islander

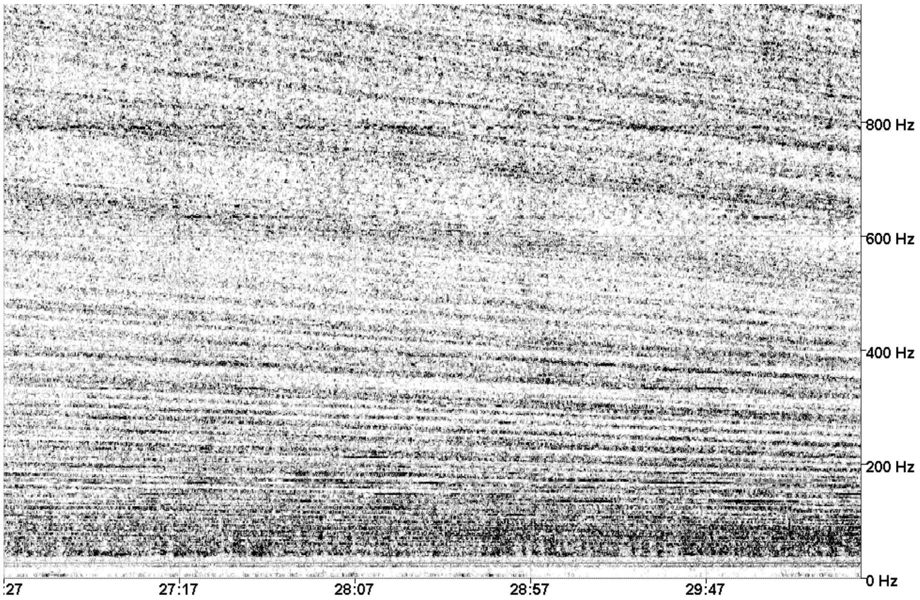

FIGURE 5.32. Sample diesel spectrogram with low frequency rumble (40 – 90 Hz), and rotating machinery lines at 164 and 785 Hz. OBH CL05, file 6DCD0728 (FFTSize 16384, real samples 16384, overlap 8192, normalized).

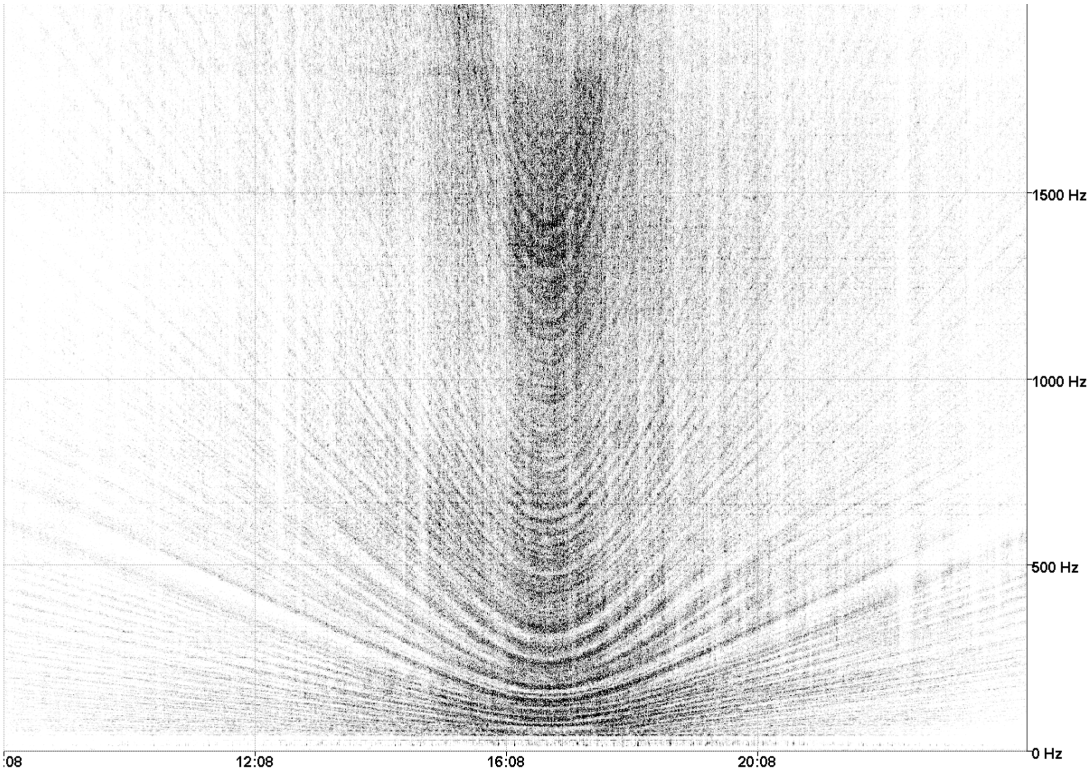

FIGURE 5.33. Lloyds' mirror interference pattern from CPA at 03:40 4 Aug. OBH CL05, file 6DCD0780 (FFTSize 16384, real samples 16384, overlap 8192, normalized).

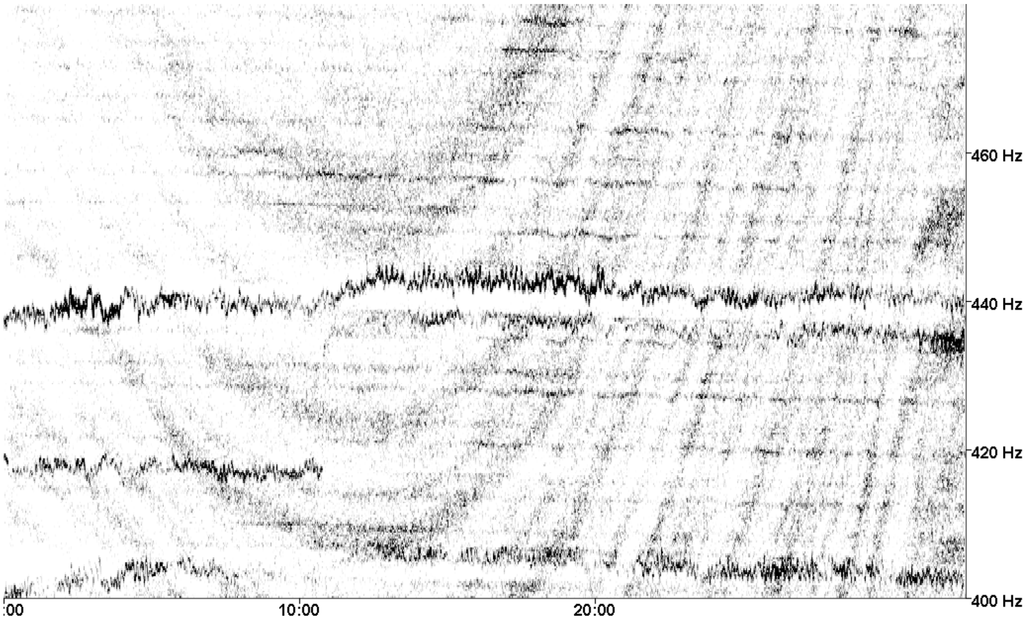

FIGURE 5.34. Expanded spectrogram view of source at 22:00 20 Jul. Note the two sources at ~440 Hz, one of which increases in speed at ~ minute 12. OBH CL10, file 71900173 (FFTSize 65536, real samples 65536, overlap 32768, normalized).

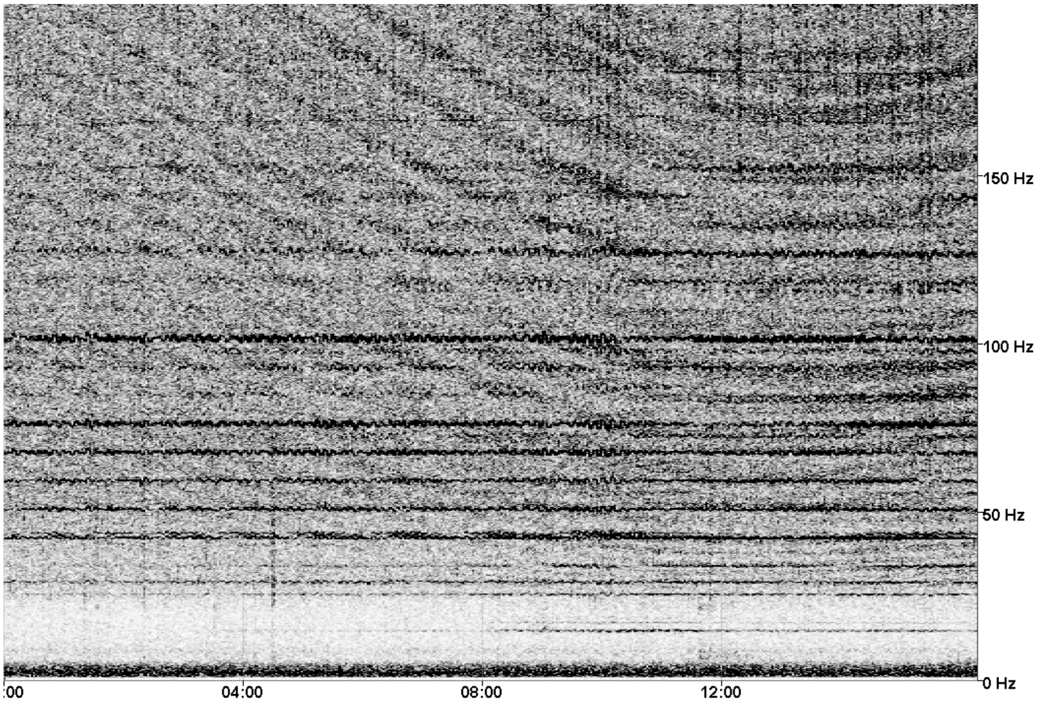

FIGURE 5.35. Spectrogram of a large diesel, potentially with 50 Hz power plant - probably Norseman. OBH CL35, file 527D1055 (FFTSize 16384, real samples 8192, overlap 8192, un-normalized).

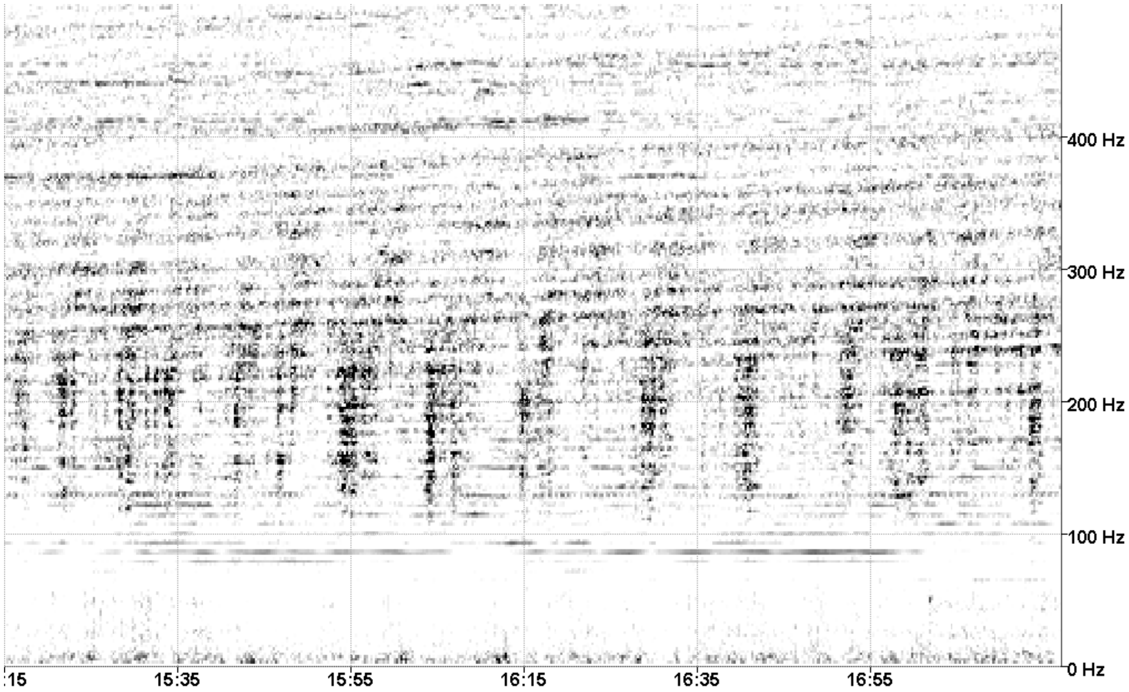

FIGURE 5.36. Slow diesel @ 2220, 5 Aug 07, OBH A01-CL5, File 6DCD0857 (FFTSize 16384, real samples 16384, overlap 8192, normalized).

Significant Shipping Events from Other Near-Shore OBHs

The OBH's closest to shore generally detected more vessel traffic than recorders further offshore. It appears that much of this activity is related to small fishing, hunting, and pleasure vessels. Figure 5.37 shows a spectrogram of this type of traffic. The rapid variations in frequency are caused by the boats moving in the waves, changing speed and changing course. In this case the detector locked onto the 61 and 49 Hz lines. In the future a small boat detector will be added that looks for rapid variability in the signals. The spectral levels of the lines in this spectrogram are below the 95% ambient level, at approximately 75 dB.

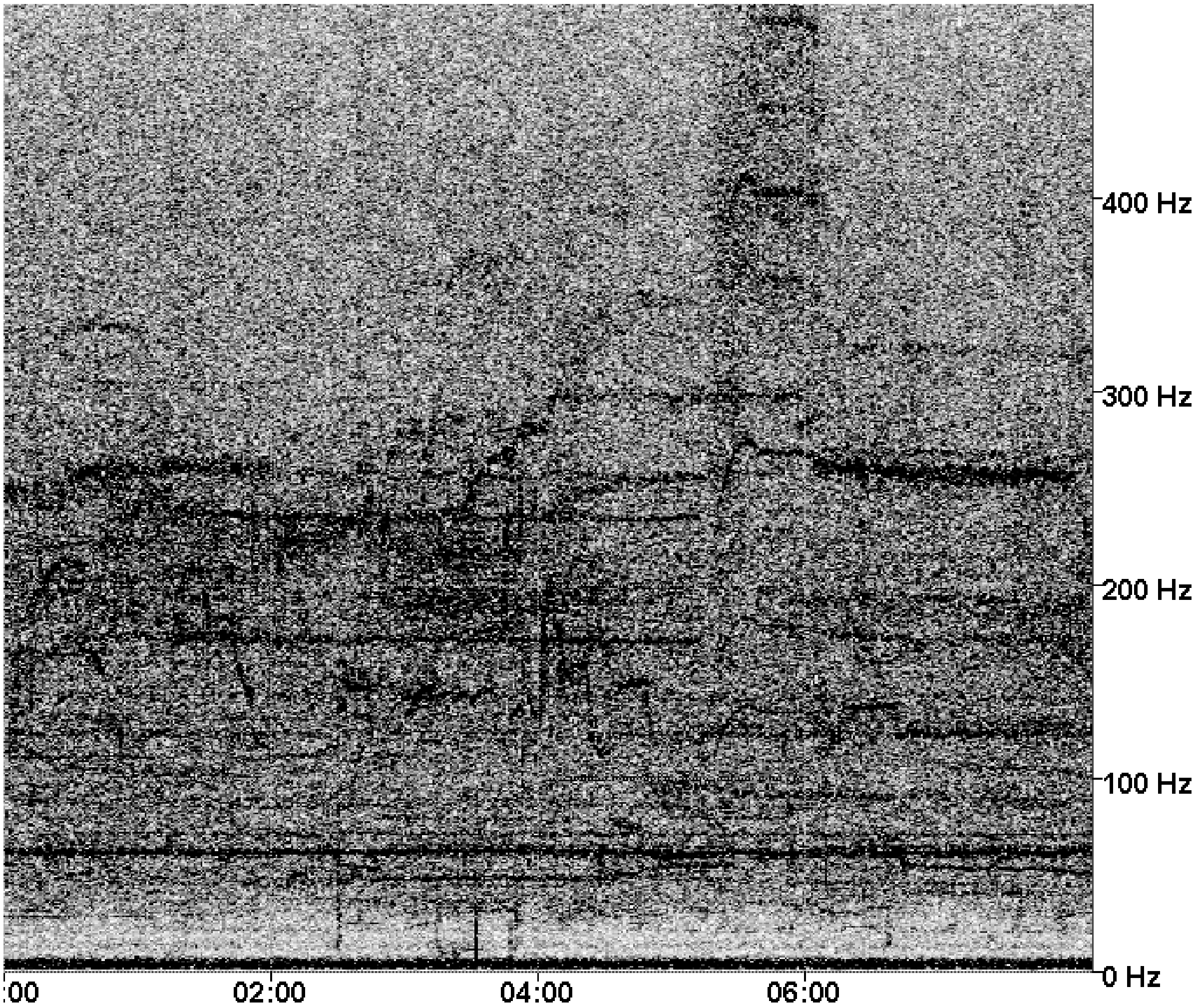

FIGURE 5.37. Spectrogram of small boat traffic, B05R, file 461E1022. (FFTSize 8192, real samples 8192, overlap 4096, un-normalized)

Significance of Detected Shipping Levels

To understand the significance of the shipping detections one needs to compare the signal levels detected to the intensity of other sound in the ocean. Figure 5.38 shows seasonal ambient noise curves for CL10, with the peak shipping noise SPLs from the CL line overlaid. From this plot it can be concluded that as expected, shipping is the dominant noise source when present. For some vessels the signals are almost 40 dB above the mean ambient noise.

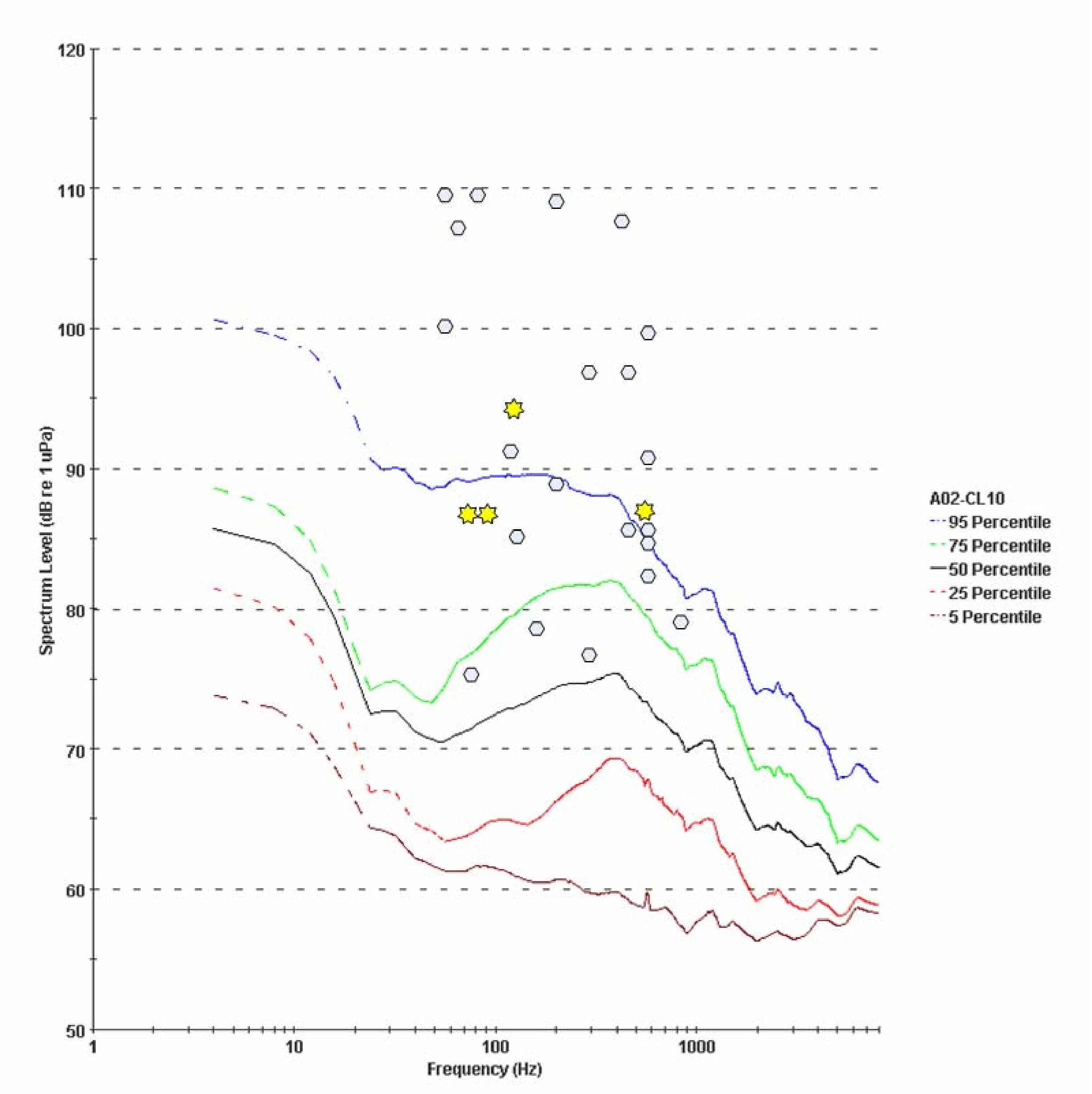

FIGURE 5.38. CL10 ambient noise with shipping peak SPL overlays; gray hexagons are the peak SPLs detected along the Cape Lisburne line that are not related to Shell's seismic vessels. The yellow stars are associated with the Norseman and American Islander.

Another way that shipping can be viewed as significant if it has a measureable impact on the ambient noise. The amount of shipping detected was very low. For instance, possible shipping was only detected twice on CLN80 beside during deployment and recovery. The OBH with the most shipping activity B20. That OBH had shipping detections on 12% of the files. At this level, we'd expect to see an impact as either an overall increase in the 95% percentile of the ambient noise, or as tonal spikes below 1 kHz due to the shipping. Appendix I shows no tonal spiking in any of the plots. Table 5.8 shows that there is no correlation between the amount of shipping and the peak ambient levels. There is a definite correlation with peak noise levels and distance from shore however.

Table 5.8: Quantity of Shipping Detection compared with maximum ambient levels

OBH	**Percentage of Files with definite shipping detections**	**Peak SPL of the 95 Percentile Ambient Noise Curve**	**Peak SPL of the 5th Percentile Ambient Noise Curve**
CL05	0.84	108	76
CL10	0.92	96	74
CL15	0.22	106	76
CL20	1.04	106	78
CL35	0.68	87	75
CL50	0.72	86	72
CLN40	0.04	97	76
CLN80	0	104	82
PL05	3.04	110	80
PL10	1.04	98	75
PL15	1.40	107	79
PL20	1.80	102	79
PL35	2.11	99	78
PL50	1.40	103	81
PLN40	1.24	95	77
W05	3.62	128	89
W10	1.84	119	89
W15	2.29	105	85
W20	1.96	104	84
W35	0.71	96	80
WN40	0.25	97	76
B10	7.8	119	85
B15	7.44	116	84
B20	12.8	93	74
B35	1.43	90	75
B50	0.67	88	70

Biologics

This section documents the detections of animal-generated sounds as provided by the automated system and validated by manual analysis. The objective of the processing was to determine where the three main species: bowheads, walruses and belugas were present throughout the summer and fall of 2007. The analysis focussed on determining when each species was present, and the relative magnitude of their acoustic activity. The acoustic recorders can only detect vocalizing animals, and the rate of vocalization could vary between individuals and in time. Consequently the distributions discussed in the following are actually vocalization count distributions that can only be correlated with relative animal distributions within a species under the assumption of uniform rates of vocalization. Numbers of calls per species should not represent relative abundance between species.

The results presented here were generated using the data processing stream described in the ***Analysis*** section (***Processing Overview***, Biologics). Marine mammal call classifications were complicated by similarity of calls by different species; for example the similarity of walrus grunts and certain bowhead calls has been discussed previously.. The full call repertoires from most of the species present in the Chukchi are not fully known. The call detection count results presented here considered only known call types. The sound recordings contain several call types not yet confidently attributed to species. Further research on species repertoires would be useful for improving the type of analysis that is presented here. The uncertainties in results arise mainly from the first point: that similarity between call types leads to some misclassification. Unknown or unassigned call types would not be attributed to presence of a species so this analysis could have undercounted or missed entirely the presence of a species. It is known that repertoires for some species are known to change temporally and spatially so this problem could also lead to spatial biasing of counts.

A manual validation of most automatic call classifications was performed using personal knowledge, peer reviewed literature, and sound samples or personal communications with other expert scientists. The manual validation process was applied to recording times during which detections rates were large. The bar charts of number of detections per file (each file contained 31 minutes of sound recording) were then overlaid with check marks or crosses to show where the data were manually validated. Further to this, detection counts were summed by week to produce relative distribution maps. On average, three files were examined for each week of data per species per recorder. If calls were not found by the manual review, for the species auto-detected, the call count values used to generate the distribution maps were changed to zero. In cases where manual validation found misclassification, for example bowhead calls misclassified as walrus, the relative numbers were adjusted to the manual validation count ratios. The manual corrections are included in the distribution maps but not the bar charts.

The automatic detection algorithm used in this study was at least 99% as effective at finding events as a manual operator. A manual review of 700 data files (360 hours of recording in which the automatic detector indicated no detections was manually found to include 3 files with faint calls. The signal to noise level of those calls was below the threshold (6 dB) we had set for the automatic detector and hence this result was expected. The validation of accuracy of species classification was more difficult. The manual of classification reviewed over 50% of the call count peaks. Only 65% of the bowhead calls were correctly classified. Many of the incorrectly classified bowheads occurred off Point Lay where large numbers of walrus calls at PL05 and PL10 were classified as bowhead calls.

The majority of false detections in the bowhead counts were due to grunting sounds from walruses. In some cases walruses had not been detected at all because none of the knock-type sounds, unique to walruses, were present. Other false detections of bowhead whales occurred from bumping sounds. False detections of beluga whales usually resulted from higher frequency tapping or metallic noises, possibly from the anchor chains and sometimes from walrus bell calls. Walrus detections were underestimated overall due to our exclusion of the grunting sounds – automatic detections of walrus calls required knocks to be present.

Total Detections

Figure 5.39 shows the total number of detections collected by all OBHs. The trend shows a peak of vocalizations at mid-season and far fewer at the beginning and end of the deployments. The bowhead migration is clearly visible as the series of peaks in Oct.

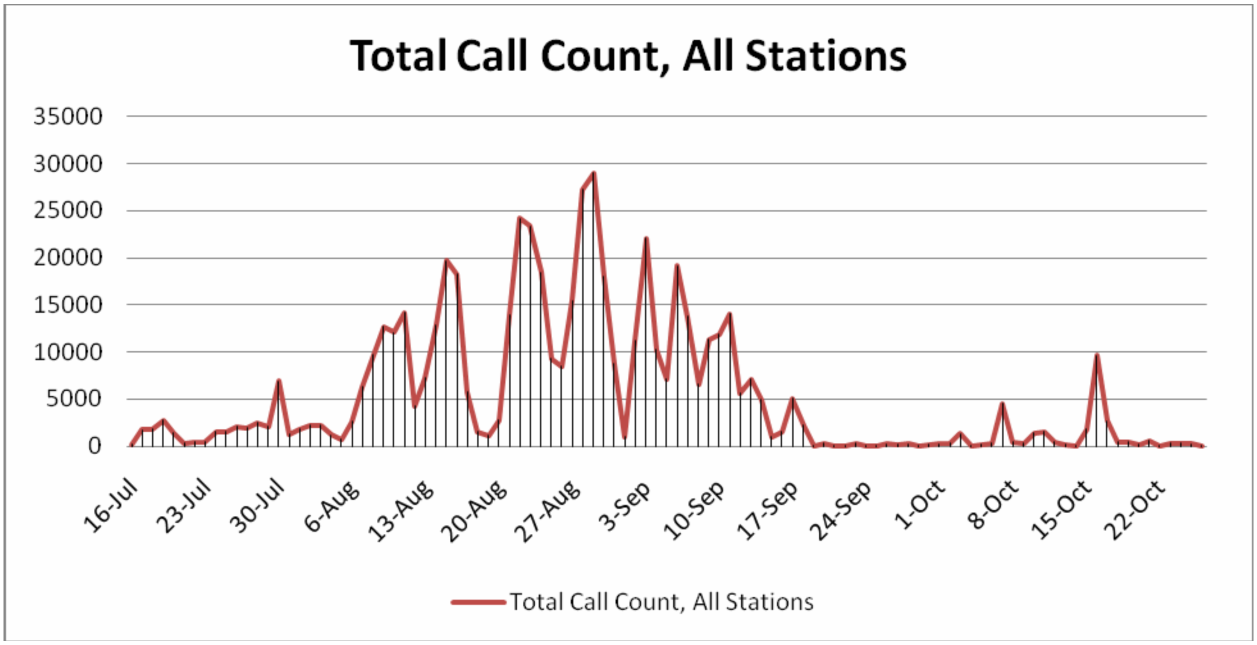

FIGURE 5.39 Total vocalization counts per day, summed across all OBHs through the 2007 summer deployment period. Counts are not adjusted for numbers of operating recorders.

Call count rates were found to be negatively correlated with ambient noise levels. Ambient noise increased in fact appear to drive nearly all of the dips in the call counts (ref FIGURE 5.40). This observation suggests that call counts are much lower than would be found if ambient noise masking of calls was not present. Count adjustments based on ambient levels may be appropriate but that was not applied here.

The primary period of seismic activity recorded by the OBHs was 29 Aug – 10 Sep. The total call counts shown above do not indicate any large changes in this period that do not correlate with the ambient noise fluctuations. This is further demonstrated by looking at the results for the OBH at Point Lay North 40. This unit was the only one to consistently receive seismic SPL's about the 120 dB level, and there is no indication of change in the vocalizations during this period.

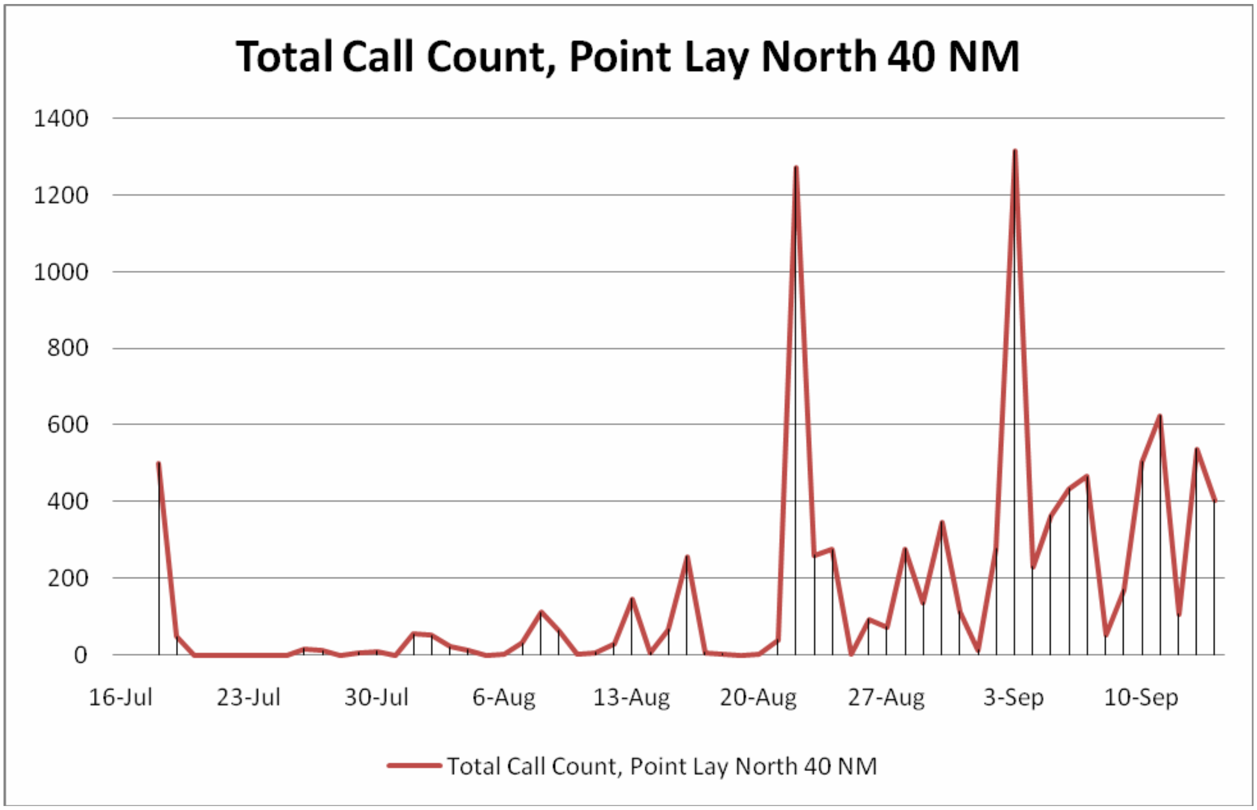

FIGURE 5.40. Daily vocalization counts at PLN40.

Belugas

Types of Calls Detected

The beluga processing defined three call types that capture the majority of the vocalizations from the 'canaries of the sea'. The call definitions are:

1. Call: This definition covered the long warbles often found at the end of a beluga call. It was defined as:
    a. Duration: 0.6 to 6.0 seconds
    b. Frequency Coverage: 1200 – 2400 Hz, centered at 1800 Hz.
    c. Shape Characteristics: Moan, with no repeats and able to occur alone.
2. High Call: This definition covers the higher frequency range of the belugas, with a very similar definition to Call:
    a. Duration: 0.2 to 3.0 seconds
    b. Frequency Coverage: 2400 – 6000 Hz, centered at 3200 Hz.
    c. Shape Characteristics: Moan, with no repeats and able to occur alone.
3. Fast Sweep: This vocalization is a rapid FM sweep, defined as:
    a. Duration: 0.2 to 0.6 seconds
    b. Frequency Coverage: 400 – 3000 Hz, centered at 1500 Hz.
    c. Shape Characteristics: FM, with no repeats and able to occur alone.

Figure 5.41 shows a sample spectrogram of beluga vocalizations that displays all of these call types. It also shows significant energy in the "call" type vocalizations well below 1200 Hz. It was decided not to process this region since it overlaps too much with other species. The higher frequency content of the beluga calls allowed reliable separation of this class of calls from the other species.

FIGURE 5.41. Sample spectrogram of beluga vocalizations from B15, File 00EA0373. (FFTSize 8192, real samples 2048, overlap 1024, un-normalized).

Detections at Barrow

Figure 5.42 and Figure 5.43 show the detection results for the belugas along the Barrow line of the net array for the first and second deployments, respectively. These results were very sparse, with the species only appearing in any sizable numbers early in the season. A group of belugas was also detected at B05 on the second deployment. The green check mark symbols indicate detections that were manually validated. See Appendix L for tables of the validation data. Figure 5.42 also shows three instances of false detections of belugas. On B50, this results from faint bell calls of walrus in the 500 Hz range that are not associated with any knock type sounds. If these bell calls had been of lower frequency, they could have been misclassified as bowhead. The incorrect identification of belugas on B35 may have been a result of very close proximity walrus grunts that had frequency content as high as 1400 Hz. On B10, a loud squeaking self-noise, possibly produced by movement of a float or frame of the OBH, was classified as beluga whistles. Some walrus sounds also occurred at this time.

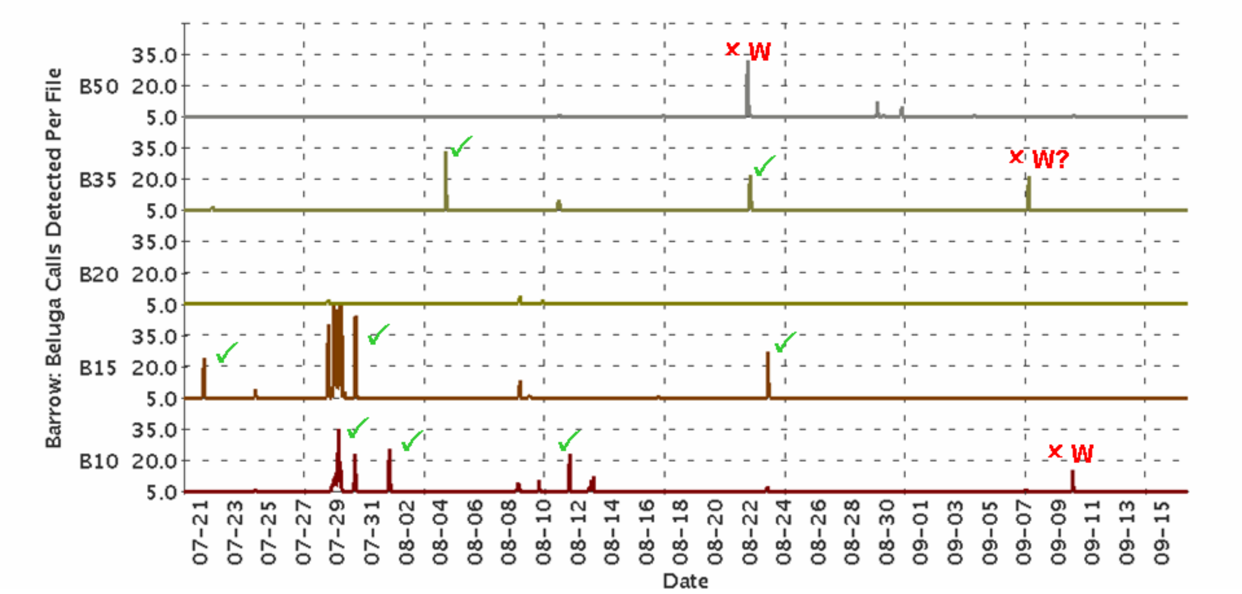

FIGURE 5.42. Number of beluga calls per file, Barrow line, first deployment. Peaks with green checks are events that have been manually validated. Events marked with a red 'W' have been checked and found to be walrus.

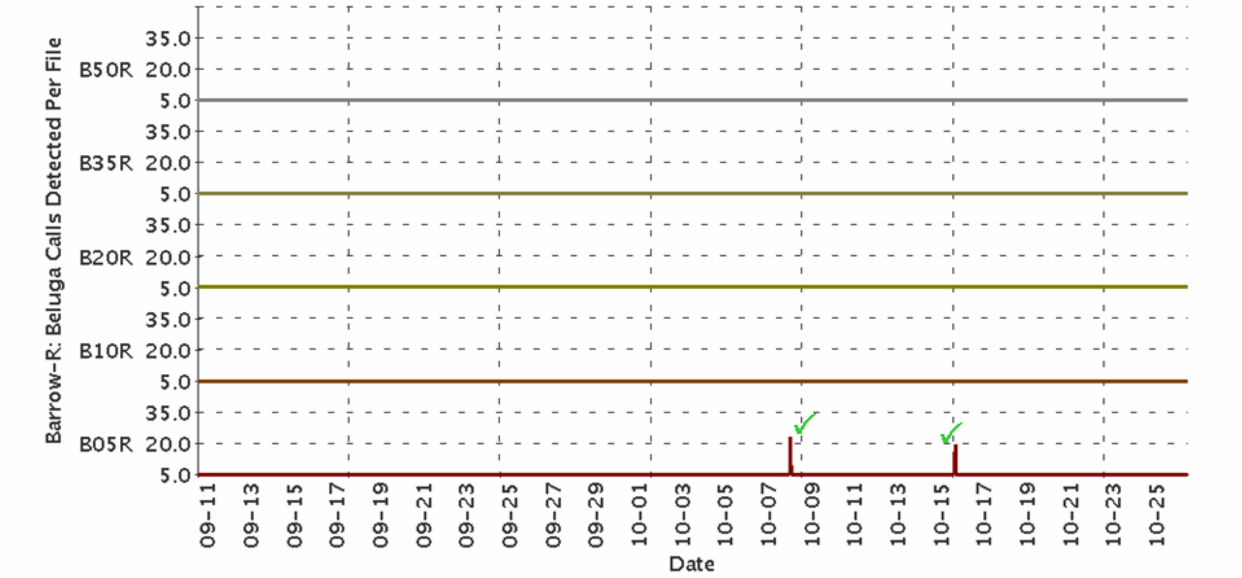

FIGURE 5.43. Number of beluga Calls per file, Barrow line, second deployment. Peaks with green checks are events that have been manually validated.

Detections at Wainwright

Figure 5.44 shows the detections along the Wainwright line during the first recorder deployment only. There were no significant beluga detections during the second deployment (Figure 5.45). The misclassification of walruses as belugas on WN40 occurred as a result of repeated 450-600 Hz bell calls without knocks. Sjare *et al*. 2003 state that bell calls are rarely heard without at least one knock preceding the bell, but the present Chukchi recordings show this is not always the case (Figure 5.46). This cause of misclassification could be treated by neglecting or negatively weighting importance of low frequency energy within the beluga classifier.

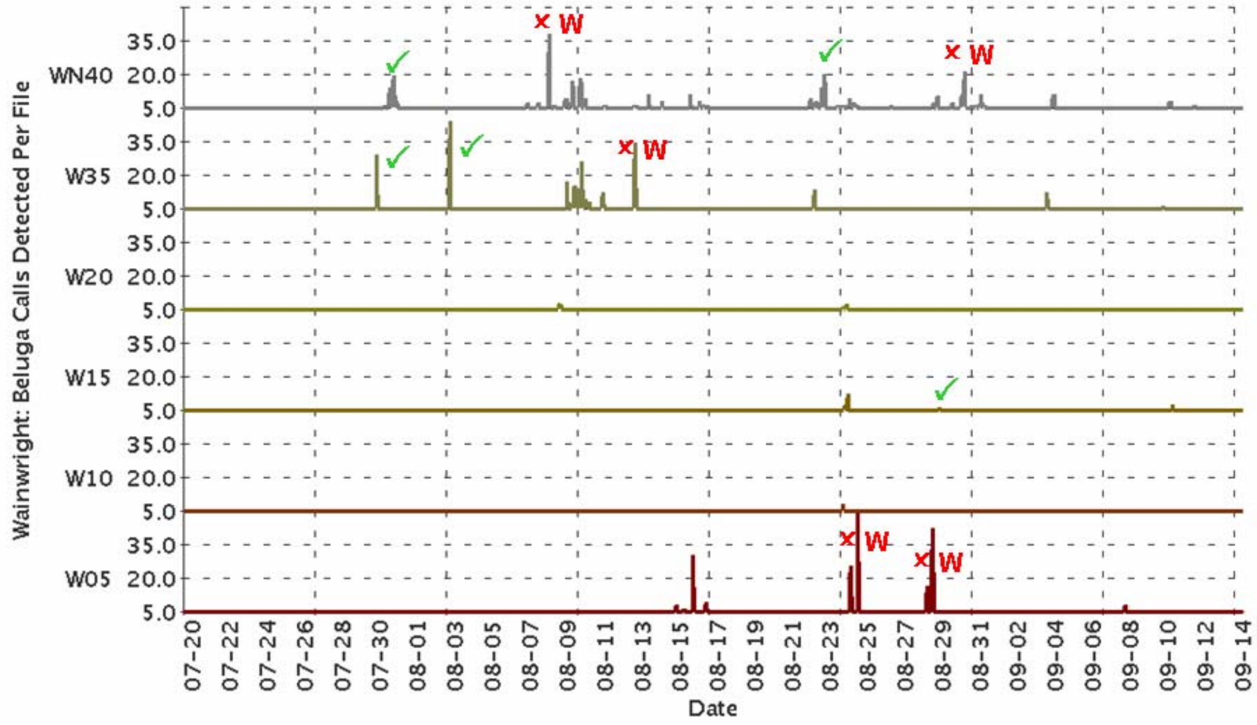

FIGURE 5.44. Number of beluga calls per file, Wainwright line, first deployment. Peaks with green checks are events that have been manually validated. Events marked with a red 'W' have been checked and found to be walrus.

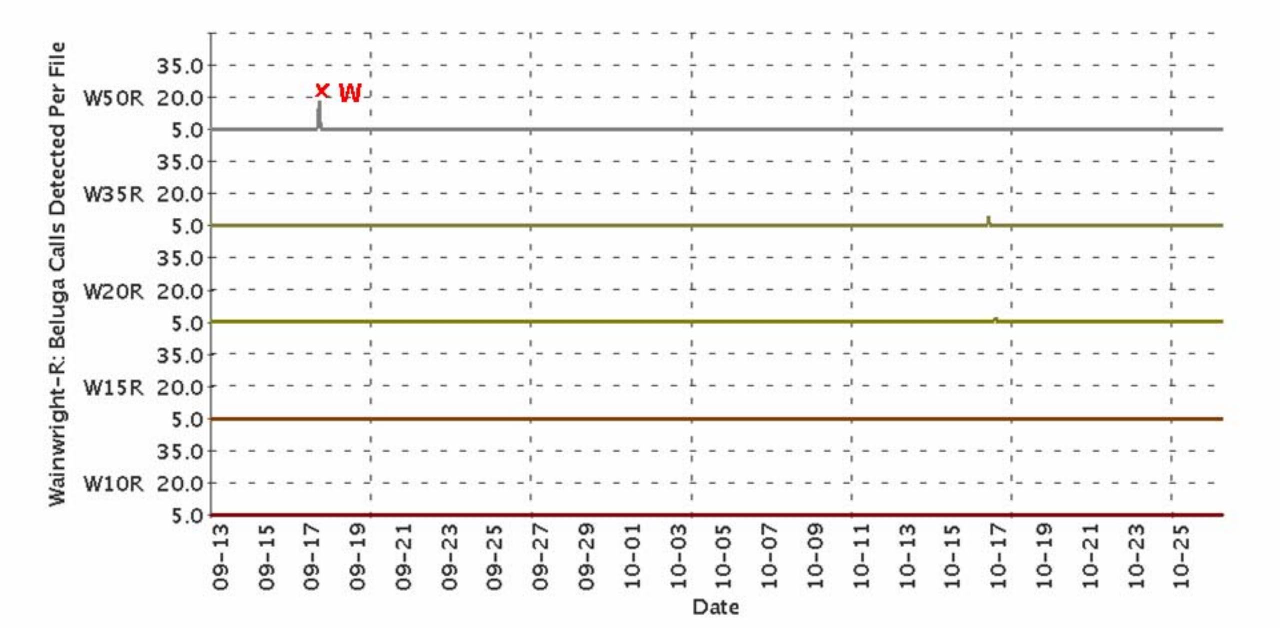

FIGURE 5.45. Beluga detections at the Wainwright line, second deployment. Events marked with a red 'W' have been checked and found to be walrus.

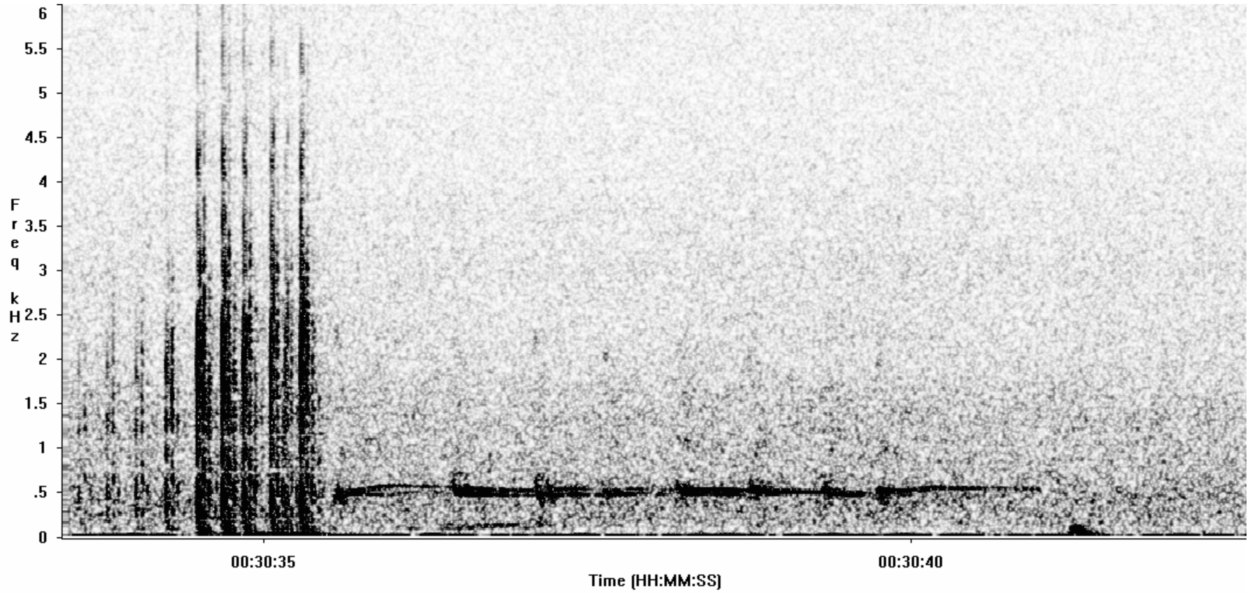

FIGURE 5.46. Walrus bell calls that did not have a knock directly associated with each bell tone, though knocks do occur before the train of bell calls.

Detections at Point Lay

There were no significant detections of belugas from the Point Lay OBHs.

Detections at Cape Lisburne

There were no significant detections of belugas from the Cape Lisburne OBHs.

Summary

Very little beluga activity was detected in 2007, and was limited to the Barrow and Wainwright lines and most detections occurred in the last week of Jul and first week of Aug.

Belugas were detected at Barrow on the 15 mile recorder (B15) 21 Jul, on B10 and B15 on 29 Jul - 1 Aug, on B35 4 Aug, then back at B10 on 11 Aug, and on B15 and B35 on 23 Aug. No beluga calls were received at Barrow in Sep, but two groups were detected on Oct 8 and Oct 15 on B5.

Belugas were detected on the Wainwright line at W35 on 29 Jul and 3 Aug. Later detections on the WN40 (90 miles offshore) and W15 were made respectively on 23 and 29 Aug. No further detections were made there.

No beluga detections were made on the Cape Lisburne or Point Lay lines.

The 2006 program had only deployed recorders at Cape Lisburne during Jul and Aug, so there were no data with which to compare the Barrow and Wainwright detections in 2007. However, it is interesting that the 2006 program did detect belugas at Cape Lisburne on 7 days out of the 56 days the recorders were deployed. In 2007 none were detected there.

Beluga detections were greater near-shore at Barrow and greater offshore at Wainwright. Too few detections were made to establish a definite trend, but there did appear to be a weak movement offshore from Barrow starting at the end of Jul. The distributions of beluga calls, after manual validation, are shown in Figure 5.47.

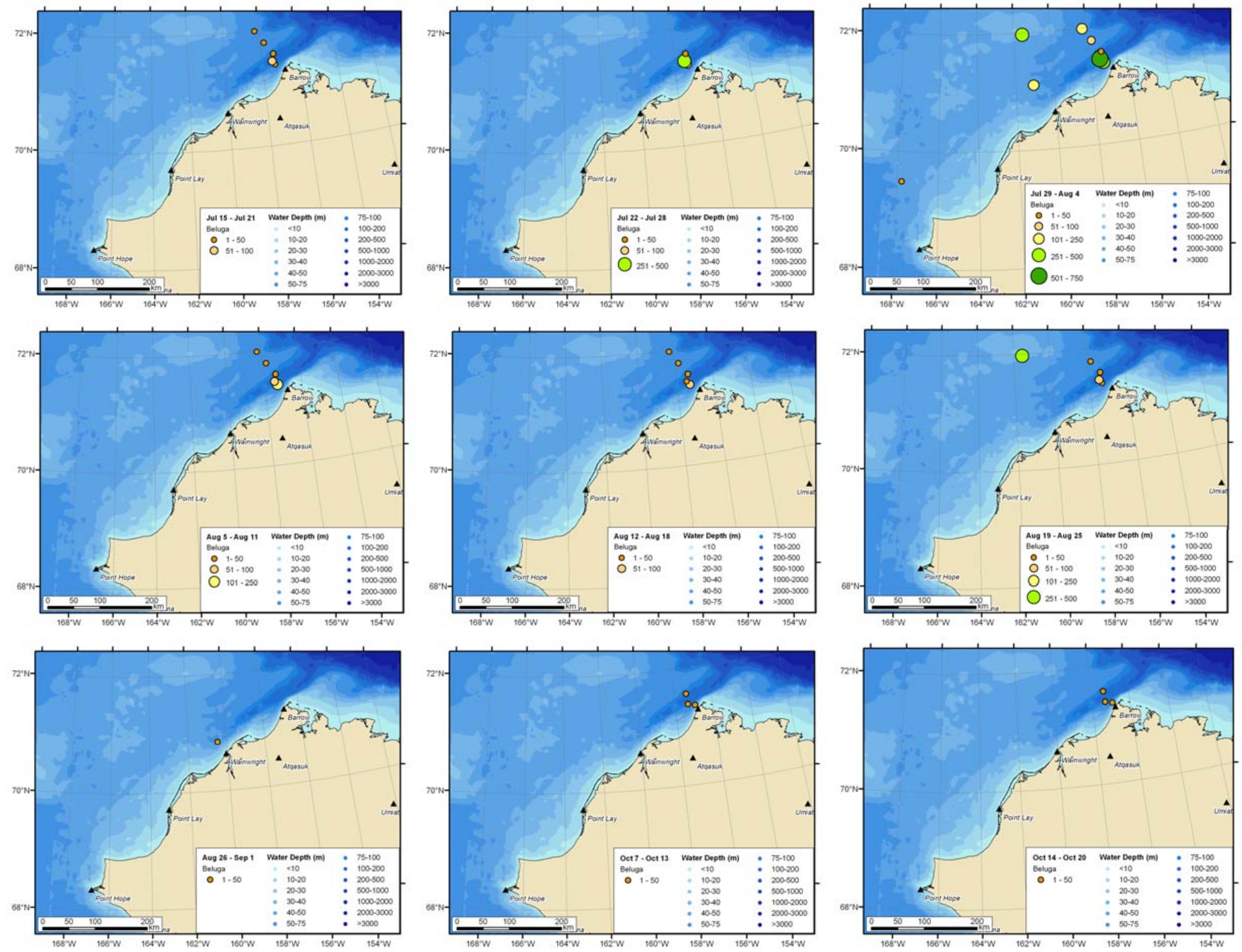

FIGURE 5.47: Beluga distributions, 2007, after manual validation.

Bowheads

Types of Calls Detected

As noted earlier (see ***Analysis***, ***Processing Overview***, *Biologics*), the frequency content and durations of bowhead vocalizations and walrus calls overlapped strongly for the bowhead "ou-ou" calls and walrus grunts. As a consequence it was necessary to create quite stringent definitions for bowhead calls to avoid false detections due to walruses. In order to separate the two species the length of the complex calls was used as a key discriminator, as well as the repetition of the bowhead "ou-ou" calls versus the generally isolated walrus grunts. The bowhead call definition parameters were:

1. ”ou-ou” and related repeated calls:
    a. Duration: 0.05 to 0.4 seconds
    b. Frequency coverage: 100 – 500 Hz, centered at 300 Hz.
    c. Shape characteristics: Moan, with 2 – 4 repeats spaced 0.05 - 0.5 seconds apart, and able to occur alone. Note that this precludes finding single bowhead ”ou” sounds, which do occur; however these are much more common in walrus than bowhead.
2. Complex calls
    a. Duration: 0.3 to 7.2 seconds
    b. Frequency coverage: 25 – 3500 Hz, centered at 300 Hz.
    c. Shape characteristics: Moan, no repeats required, can occur alone.
3. Simple low calls:
    a. Duration: 1.0 to 7.2 seconds
    b. Frequency coverage: 100 – 500 Hz, centered at 200 Hz.
    c. Shape characteristics: Moan, no repeats required, can occur alone.

Figure 5.48 shows all three types of calls within a short time span. At the left hand edge there is a series of the lower-bandwidth complex calls, followed in the middle by high bandwidth complex calls mixed with a series of multi-part ”ou-ou” vocalizations. This call sequence is from B05R in mid Oct (file 1619).

A manual validation of the bowhead detections was performed by examining all larger peaks in bowhead call counts per file. The process was complicated because the recordings from this study included higher frequency content, and additional call spectral features, than previous recordings of bowheads in the summer and fall made by other researchers. The extra bandwidth provided more detail of call structure that few experts were familiar with. Bowhead call identification was based on descriptions and spectrograms provided in literature (Ljungblad *et al*. 1982; Clark and Johnson 1984; Cummings and Holiday 1987; Würsig and Clark 1993; Blackwell *et al*. 2007) as well as from sound samples found on internet databases (Macaulay Sound Library; DOSITS). The majority of past vocalization recordings available were made in late summer in the Beaufort Sea. No published data were found on recordings of bowheads in the summer or autumn in the Chukchi Sea. The "ou-ou" type calls of the bowhead occur in the 150-450 Hz range (Blackwell *et al.* 2007). Calls labeled by Blackwell *et al*. (2007) as double grunts were similar in the sense that the greatest energy was still in the 150-450 Hz band, but energy also extended above and below these frequencies. Blackwell's recordings were limited to 512 Hz maximum acoustic frequency. During manual verification, some calls were easily attributed to bowheads, but other calls were similar to walrus grunts and even sometimes knocks that occurred in pairs. It is possible that calls recorded from greater distances became distorted in time due to frequency dispersion making it more difficult to definitely label them as bowhead "ou-ou" calls. Also, the walrus grunts are poorly described in literature so many grunts or "ou-ou" like calls were labeled as ambiguous. Of the "ou-ou" calls checked, about 18% were more likely walrus grunts and not bowheads, however there were instances where both species may have been present.

Bowhead detections were made on all OBH recorders and occurred through the full monitoring period. Until recently there has remained uncertainty about the presence of bowheads in the Chukchi during summer after the eastward migration. There is some evidence including visual observations that suggests some bowheads do remain. The vocalization detections confirm their presence but do not yet suggest how many whales might be there. The acoustic results indicate a slowly increasing number of bowhead call detections along the Chukchi coast from late Jul to early Sep. Bowheads appeared in late Jul off Barrow and Wainwright, then one week later off Point Lay and Cape Lisburne. Numbers of detected calls increased along the coast off all four sub-array locations in mid-Aug, declined in late Aug and increased again in Sep. These results were partly confirmed by visual sightings from SOI vessels operating in 2007. The *Gilavar* reported bowheads near WN40 on the 25th of Aug. There is still a possibility that other species could be responsible for some of the calls. The bowhead detections in Jul and Aug can only be compared with the 2006 sampling at Cape Lisburne between 15 Jul and 9 Sep 2006. No other lines were deployed for that time period in 2006. The 2006 Cape Lisburne recordings did not detect any bowheads. This differs from the 2007 results at Cape Lisburne that show automatic detections on CL05 before Aug 18, though manually validated positive detections have only yet been done for calls as early as Aug 25. The 2007 results also showed validated bowhead detections at CLN80 (130 miles offshore) on 1 Sep.

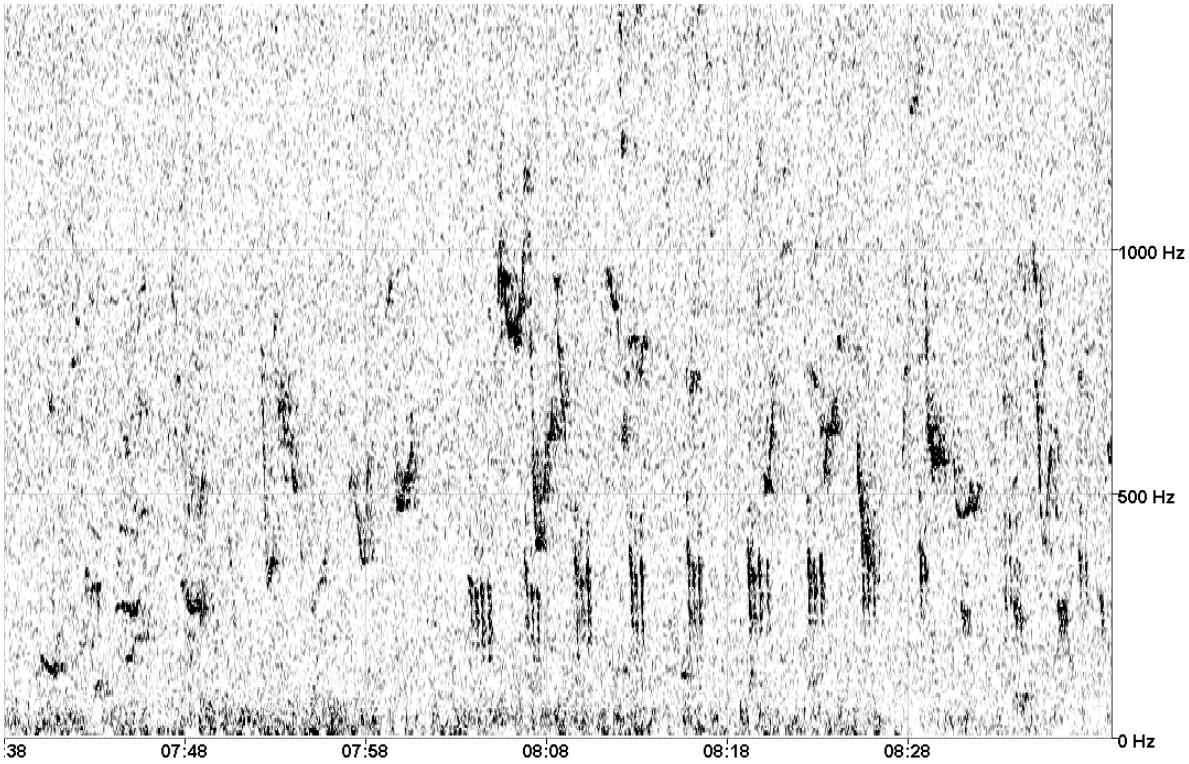

FIGURE 5.48. Bowhead vocalizations showing all three types of calls. OBH B05R, 19 Oct 2007, file 367F1619 (FFTSize 4096, real samples 1024, overlap 512, normalized).

Detections at Barrow

Detections of bowhead whales along the Barrow line are shown in Figure 5.49 and **Error! Reference source not found.** for the first and second deployments, respectively. Bowhead detections were made throughout the monitoring program, at all ranges from shore. The call types detected early in the monitoring program were mainly variations of the “ou-ou” that is common during the fall migration in the Beaufort. These variations made it difficult to perform the classification with certainty. These “ou-ou” type calls have not been previously described from recordings in the Chukchi Sea. The presence of large numbers of walruses in the Chukchi as compared to the Beaufort made it more difficult to definitely identify the species making the sounds, especially in the absence of visual confirmations. Furthermore the “ou” sounds often occurred in multiples and not just as a double. It is expected that further investigation into these call variations and possible alternate origins would have to be conducted before a firm estimate of the fraction that truly are bowheads can be established.

Approximately 13%, of the bowhead detections at Barrow were determined to be other species’s calls. Most of these misclassifications were due to walrus calls, which often occurred simultaneously with bowhead calls. The misclassification primarily occurred when the walruses were grunting but not knocking. Misclassification of walrus calls at Barrow was less a problem than it was at Wainwright due to the greater numbers of walrus there. In at least one case a humpback vocalization was encountered that was misclassified as a bowhead. This occurred because humpbacks were not in the classification options and bowhead calls were the closest match.

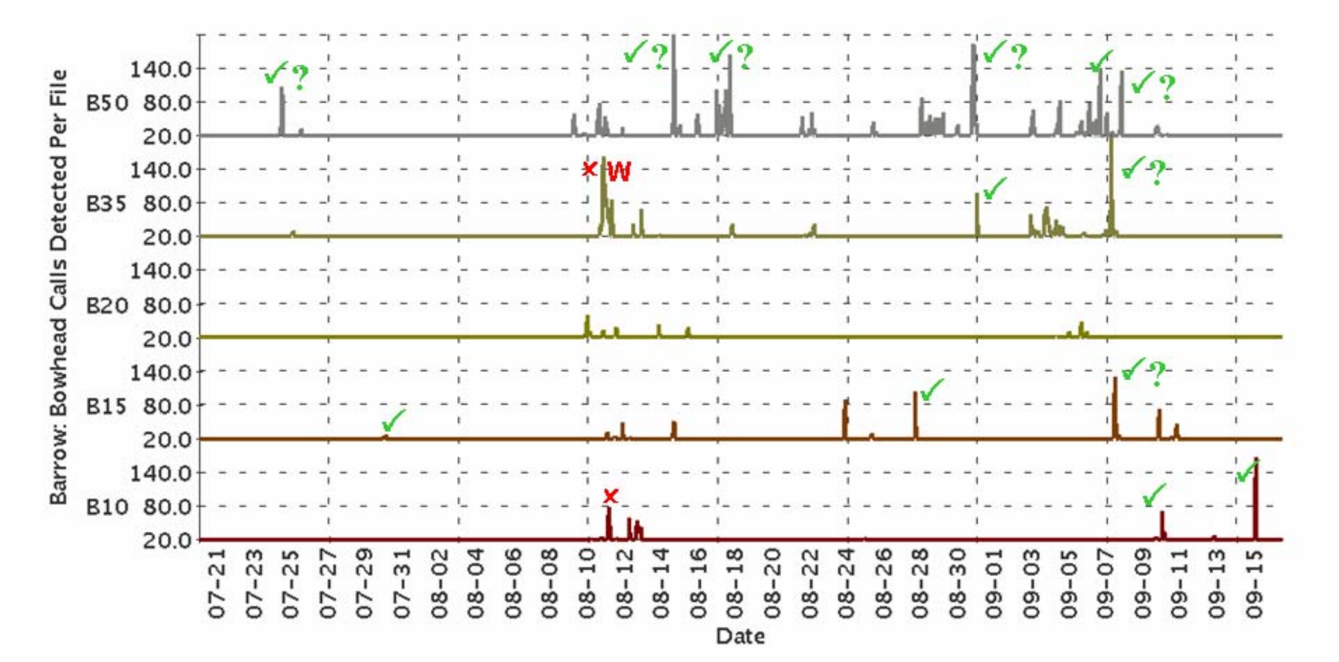

FIGURE 5.49. Number of bowhead calls per file, Barrow line, first deployment. Check marks are detections that have been manually validated, the question marks indicate there is a high probability of the detections being Bowhead, but not certain. Peaks with a red 'W' indicate walrus were present.

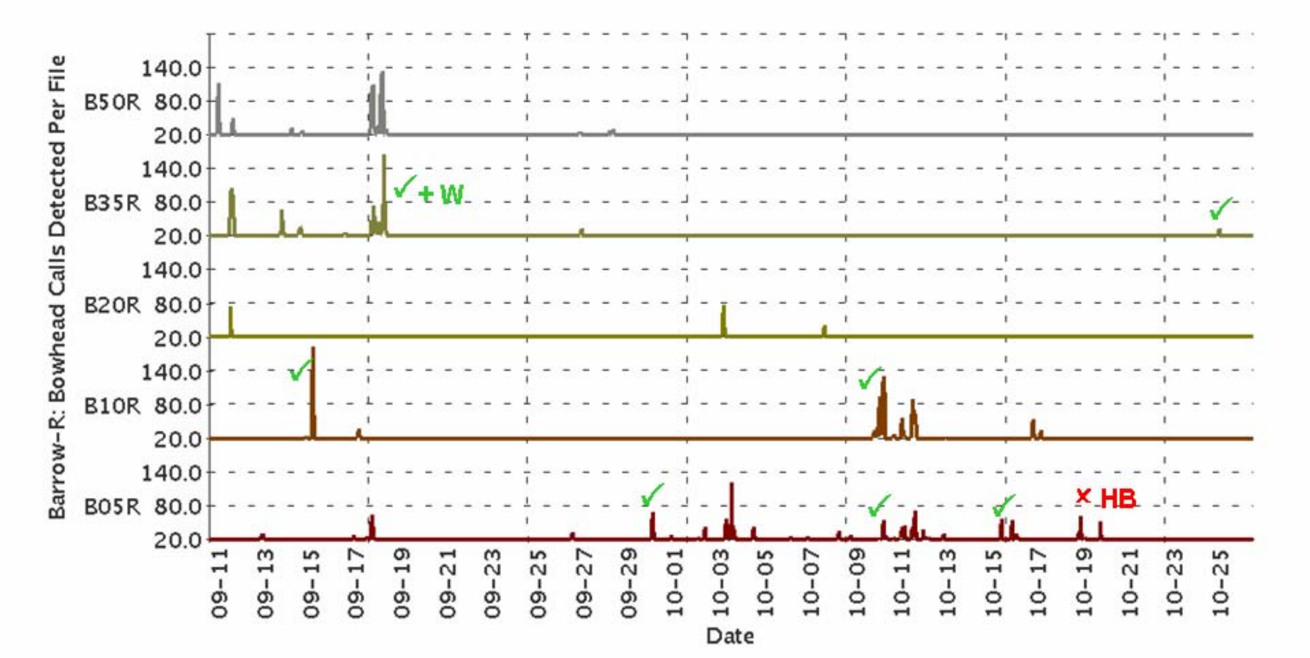

FIGURE 5.50. Number of bowhead calls per file, Barrow line, second deployment. Check marks are detections that have been manually validated. Peaks with a '+W' indicate that walrus were simultaneously present. The peak marked "X HB" indicates that the peak was manually identified as humpback calls.

Detections at Wainwright

Figure 5.51 and Figure 5.52 show the automatic bowhead detection rates on the Wainwright recorder array. Like at other sites, bowheads were detected at all distances offshore, in this case starting in early Aug. The Wainwright detections of bowheads in late Aug were more strongly influenced by misclassifications of walrus calls as bowheads than at other sites. This result is attributed to the much greater numbers of walrus calls at Wainwright that occurred in late Aug. Here walrus grunts were misclassified as bowhead grunts and there were some walrus bell calls misclassified as bowhead tonal calls. This caused bowhead counts to be incorrect (to high) on Aug 19-25 near shore at Wainwright. Also, bowhead broadband double grunt calls could have been misclassified as walrus knocks. We cannot give accurate numbers of misclassified calls without a complete manual review of those calls, and even that may not produce an accurate figure due to the close similarity (and hence difficulty at manual classification) of bowhead and walrus calls.

The second deployment recordings, from mid-Sep to mid-Oct, were less influenced by walrus calls because the large walrus groups left the area by early Sep. The second-deployment result set shows a less defined peak on 17-18 Sep and two well defined peaks of bowhead calling activity on 7 and 17 Oct. While the peaked result suggests temporal clustering of bowhead migrations, we note that these three days had unusually low ambient noise levels (ref Figure 65, Appendix E) that were responsible for the peaks. It is probable that there were bowhead calls at other times but that those calls were masked due to higher ambient noise levels. Some of the 17 Sep peaks results were not confidently classified by the manual verification due to variations of those calls from the typical "ou-ou" type. The detections on 7 and 17 Oct were confidently classified as boweads. These show fairly uniform distribution with distance to 35 miles offshore, but much lower call rates at the 50 miles station. It is likely that individual bowhead calls would be simultaneously detected on multiple recorders during the very low ambient noise periods. The actual call location distributions therefore are not well defined by the present analysis, except that they taper off rapidly beyond 35 miles offshore, and probably at somewhat less than that. A further examination of those call amplitudes could resolve the distributions more accurately. Furthermore if ambient noise masking could be reduced it might be possible to extract bowhead distributions for other times.

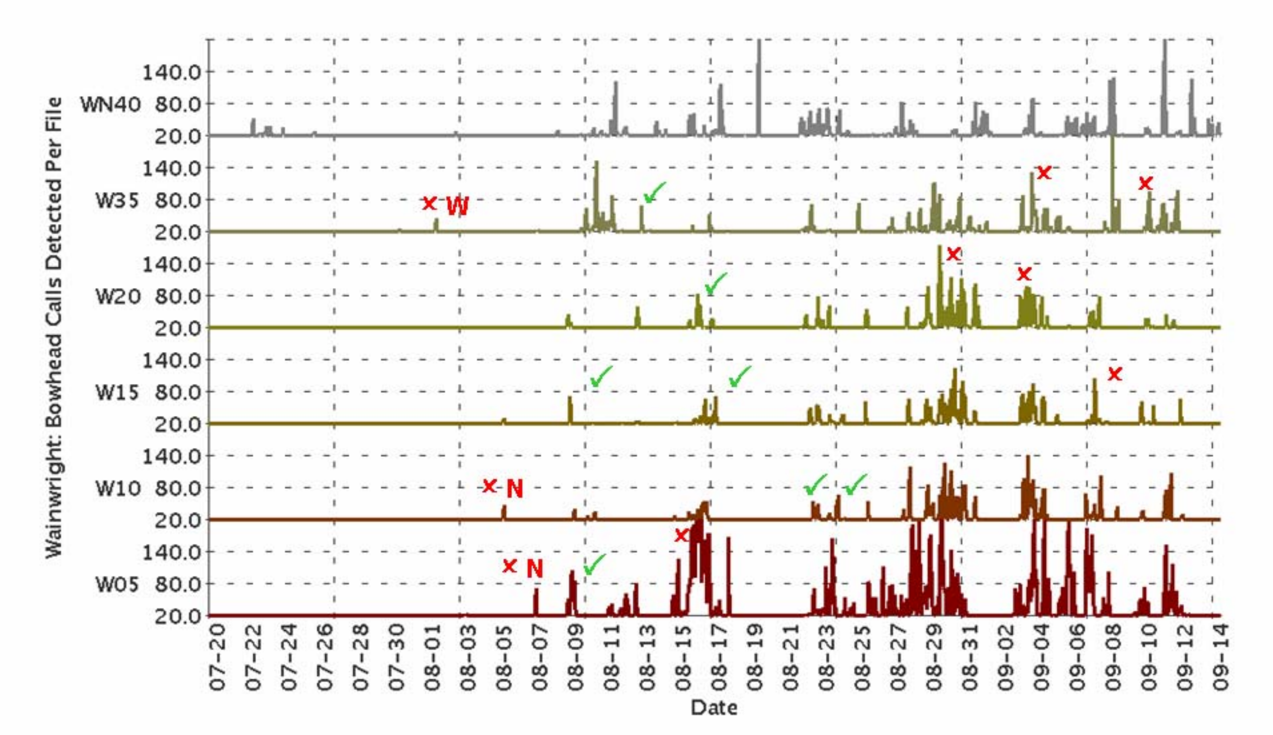

FIGURE 5.51. Number of bowhead calls per file, Wainwright line, first deployment. Check marks are detections that have been manually validated. Peaks with a red ‘W’ indicate walrus were actually present. ‘N’ indicates that noise on the system triggered detection.

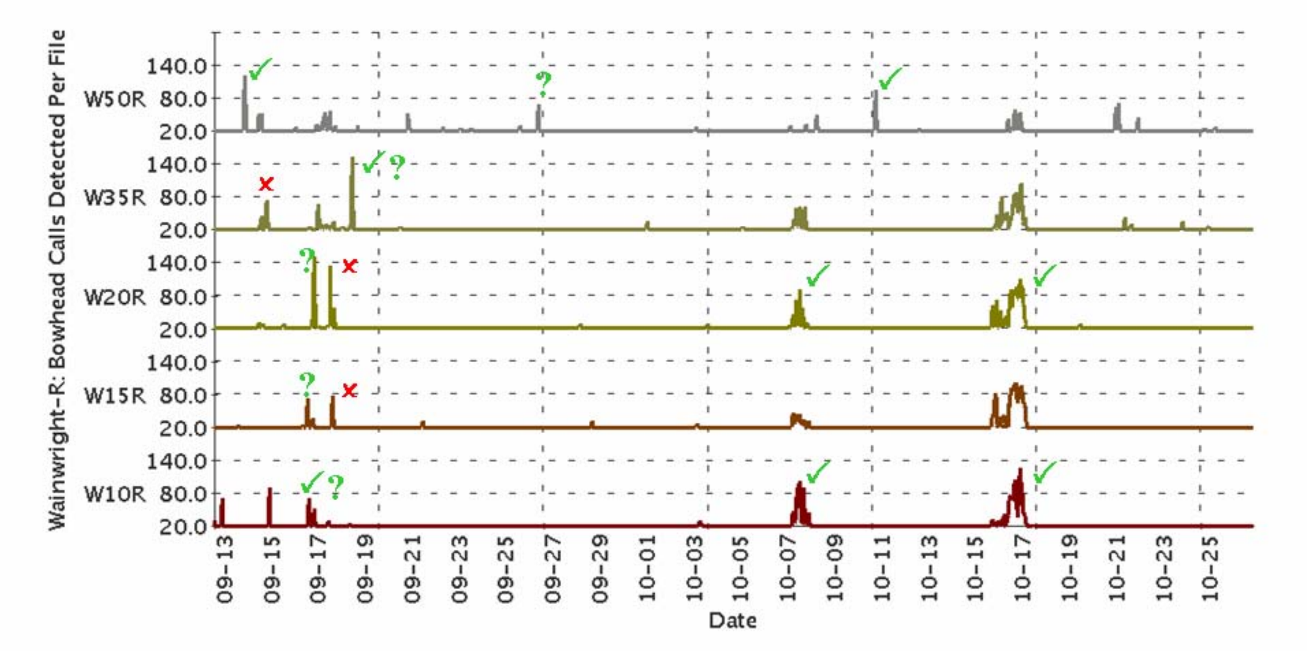

FIGURE 5.52. Number of bowhead calls per file, Wainwright line, second deployment. Check marks are detections that have been manually validated, the question marks indicate there is a high probability of the detections being bowhead, but not certain. Peaks with a red ‘x’ indicate walrus were actually present.

Detections at Point Lay

The presence of many walruses at Point Lay and Wainwright in Aug complicated the bowhead detections there. In the next section (***Walrus***) there is a discussion of walrus calls and their similarities with bowhead vocalizations. In the course of manual validation of numerous automatic detections of bowheads it was found that in most cases walrus grunts triggered the bowhead detector (see bowhead detection summary for Point Lay, Figure 5.53). Only about 17% of the peaks in the plot checked were manually classified as bowheads, and manual classifications could suffer similar mistakes. The problem occurred most frequently when the walruses were grunting but not knocking. Some walrus bell calls may also have been classified as bowhead calls. As mentioned in the beluga results, walrus bell calls were sometimes present without associated knocks. Those that were less than 500 Hz could have been mistakenly classified as bowhead calls. Gray whales were also misidentified as bowheads early in the season at PL15 and PL10 due to inadequate knowledge of gray whale calls prior to setting up the classifier. Some bowheads were detected at Point Lay starting around 20 Aug.

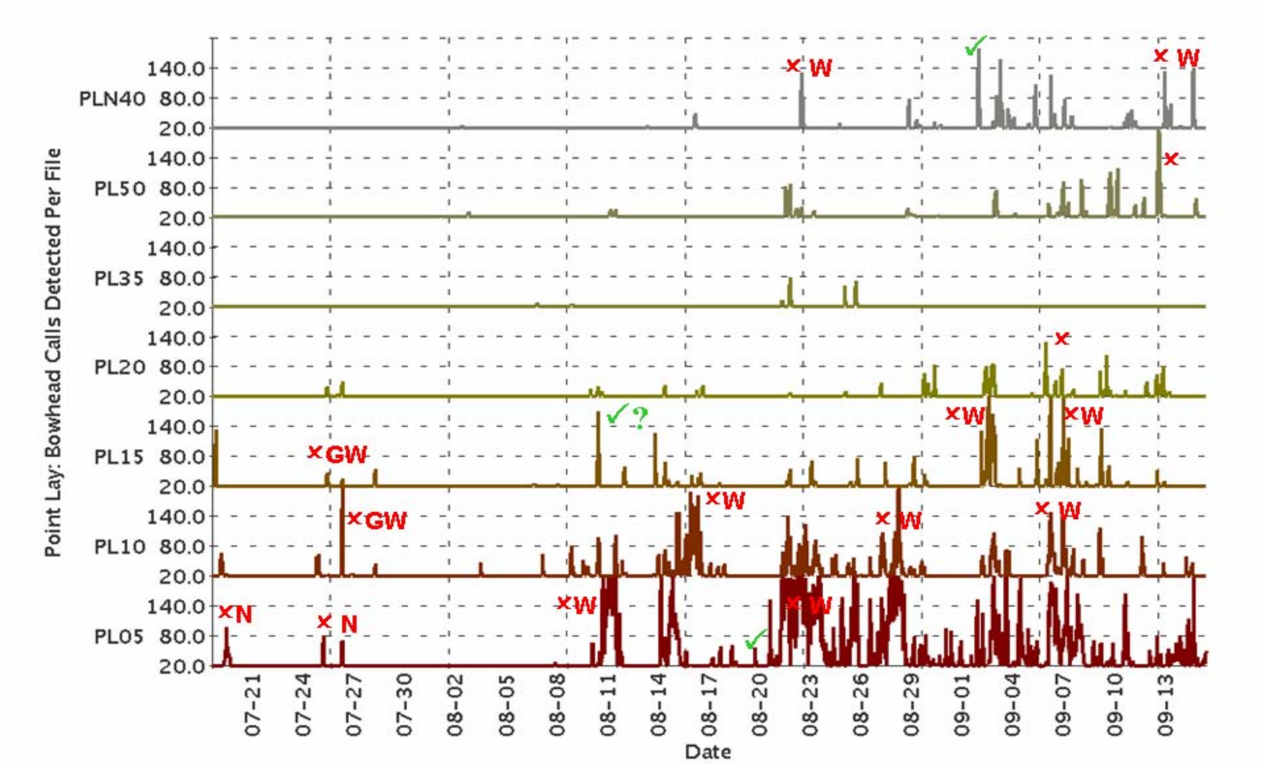

FIGURE 5.53. Number of bowhead calls per file, Point Lay line, first deployment. Check marks are detections that have been manually validated, the question marks indicate there is a high probability of the detections being bowhead, but not certain. Peaks with a red 'W' indicate walrus were actually present. Peaks with a red 'GW' indicate that gray whales were actually present.

Detections at Cape Lisburne

By late Aug bowheads were regularly detected at all ranges from shore along the Cape Lisburne line, as shown in Figure 5.54. The peaks in detections on CL05 from Aug 19-25 were indeed bowhead "ou-ou" type calls. Some sounds observed at CLN40 and CLN80 were due to noise produced by movement of the buoys due to water flow and those occasionally were misclassified as bowheads. Manual validations of automatic bowhead classifications found that 65% of those were correctly classified.

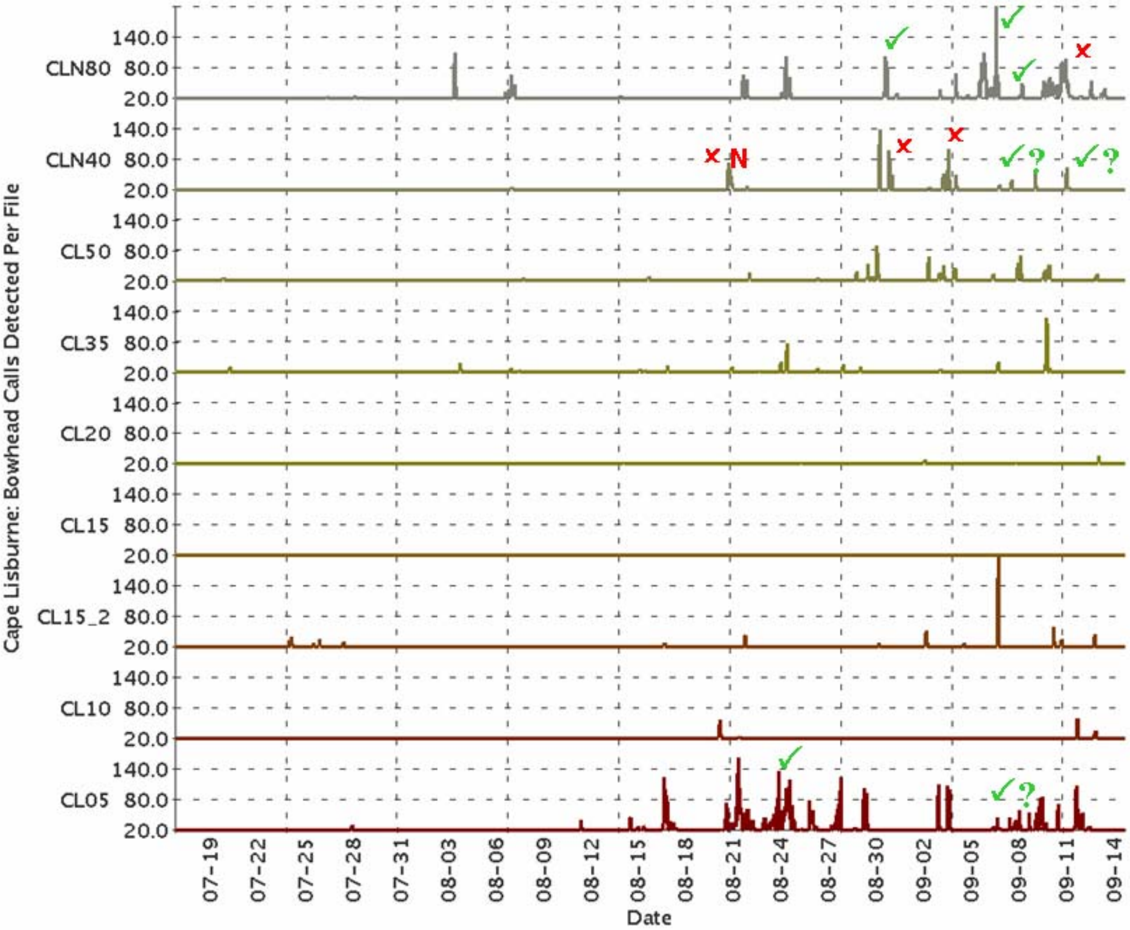

FIGURE 5.54. Number of bowhead calls per file, Cape Lisburne line, first deployment. Check marks are detections that have been manually validated, the question marks indicate there is a high probability of the detections being Bowhead, but not certain. Peaks with an 'X' indicate that other non-mammal events were detected (fish?). 'N' indicates that noise on the system triggered a detection.

Summary

Bowheads were detected on all Chukchi OBH sub-array lines starting in early Aug 2007. Early summer detections were made at Wainwright on 9 Aug, at Point Lay on 20 Aug and at Cape Lisburne on 24 Aug. These detections were made over a large area and did not have a temporal maximum. Higher numbers of bowhead call detections were made off Wainwright in Sep and Oct and these calls likely were produced by bowheads migrating out of the Beaufort. The bowhead call count rates produced by the automatic classifier were affected by large numbers of walrus present near Wainwright and Point Lay in late Aug. Many of the walrus calls were similar to bowhead calls and this led to incorrect classifications. Ambient noise also reduced the effectiveness of the classifer in Sep and Oct. Further examination of those data might produce improved distribution results.

Figure 5.55 and FIGURE 5.56 show the manually-validated and corrected distributions of bowheads for each week of the monitoring program. The correction factors were derived from the fraction of correct classifications of the bowhead classifier. These factors varied by time and location. The automatic call classifier also failed to identify bowhead calls in the presence of higher ambient noise levels. The manual validation review did not consider time periods with low detection counts, so the Sep and Oct bowhead count rates are likely underestimated except during periods of low ambient noise levels, specifically 17-18 Sep, 7 Oct and 17 Oct, 2007.

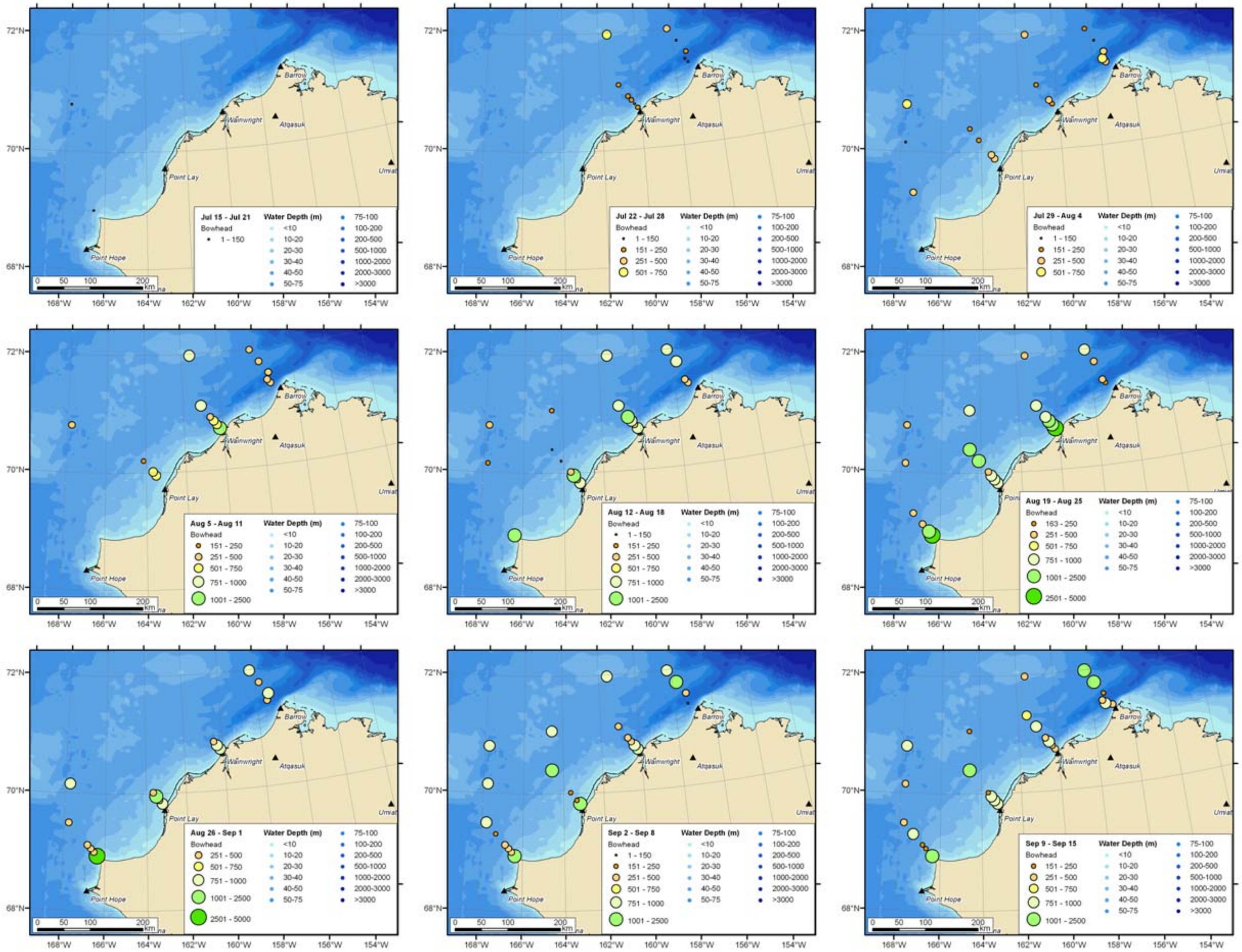

FIGURE 5.55. Weekly bowhead distributions, after manual validation, first deployment.

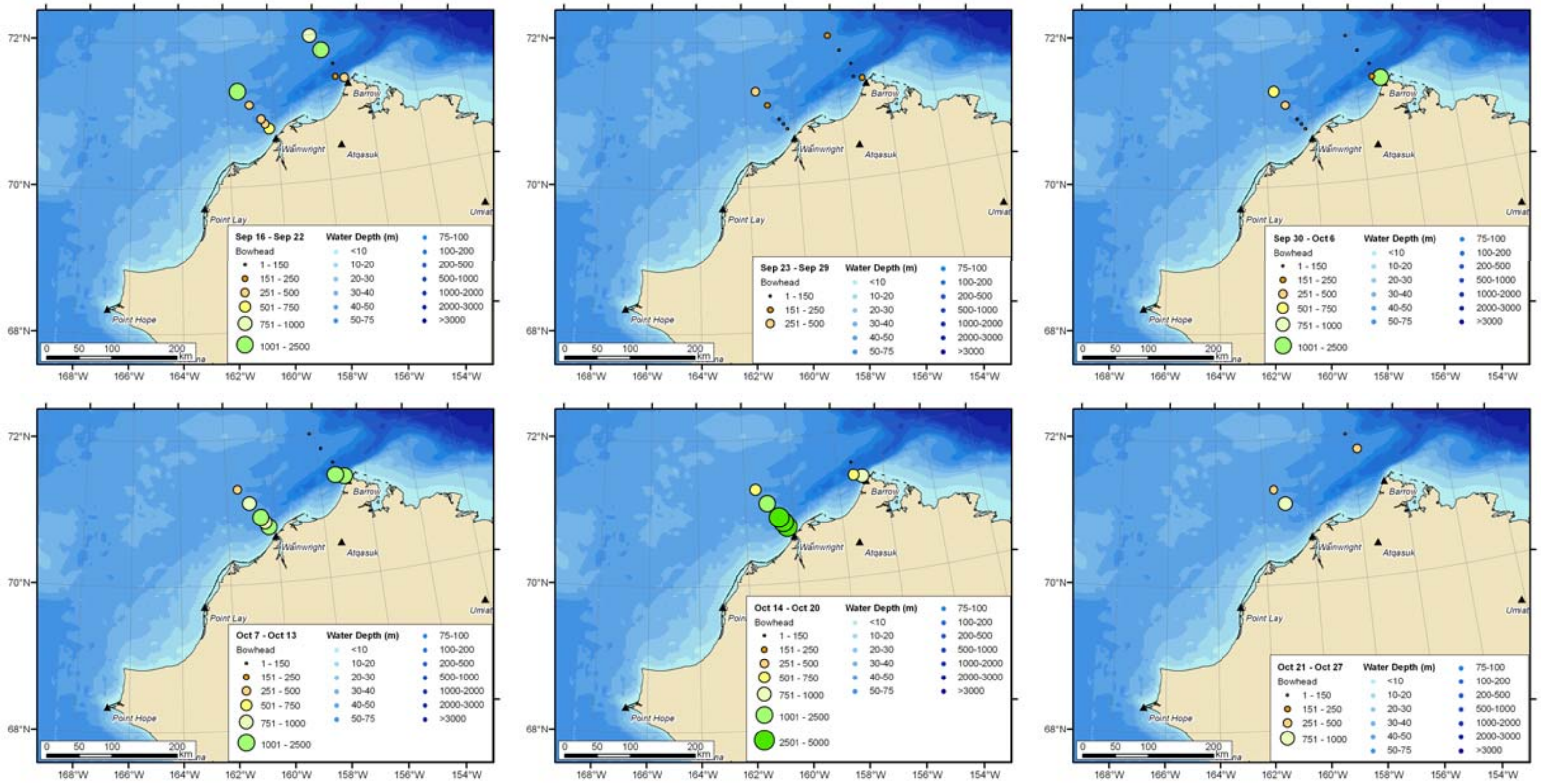

FIGURE 5.56: Weekly bowhead distributions, after manual validation, second deployment.

Pacific Walruses

Types of Calls Detected

Walrus knocks and bell calls have been widely described in the literature (Schusterman and Reichmuth 2008; Sjare *et al*. 2003; Stirling *et al*. 1987; Stirling *et al*. 1983). Walrus grunts however are widely varied and not well described. Isolation and identification of walrus calls was often complicated in the Chukchi OBH data by the presence of very large numbers of simultaneous walrus vocalizations of multiple types. It was further complicated by the classification overlap between many of their vocalizations and those of bowheads and seals. As described earlier (see ***Analysis***, ***Processing Overview***, Contours Analysis Task), an attempt was made to develop call definitions and measurements that would separate the low frequency (< 500 Hz) walrus calls from those of bowheads, but the results were not satisfactory, leading to up to 25% of bowhead call being classified as walrus and vice-versa by the automatic classifier. A sample of three types of walrus call is shown in Figure 5.57.

It was noted that during manual validation of the cases where the bowhead / walrus classification was ambiguous, trained operators relied on the presence of the metallic knocking sounds as the key confirmation of walrus vocalizations and not bowhead vocalizations. The fianal automatic classifier parameterization required walrus calls to include knocking sounds. The important features of this call type are its short duration, high frequency content, and repetition multiple times. The following call definition was developed:

a. Duration: 0.05 to 0.3 seconds

b. Frequency coverage: 500 – 3000 Hz, centered at 1000 Hz.

c. Shape characteristics: Pulses, 2 – 20 repeats with a spacing of 0.05 to .5 seconds.

If walrus grunts were present without knocks they were likely to be misclassified as bowhead “ou-ou” type calls. These walrus grunts and the bowhead “ou-ou” calls are at similar frequencies with similar duration and intercall spacing. A human listener can often distinguish the difference between some walrus grunts and bowhead “ou-ou” calls based on greater reverberation presence for bowhead calls, but the automatic classifier used in this study cannot yet do that. Some broadband bowhead double grunt type calls, especially when they were in groups of three or four were misclassified as walrus knocks.

The classification approach used in this study attempted to minimize the probability of false classifications by omitting calls that were similar to bowhead calls. The negative aspect of this approach was that some walrus calls were not counted. We estimate that the number of “ou-ou” calls from walruses may have been underestimated by up to a factor of ten. Work remains underway to automatically distinguish this type of call between bowheads and walruses.

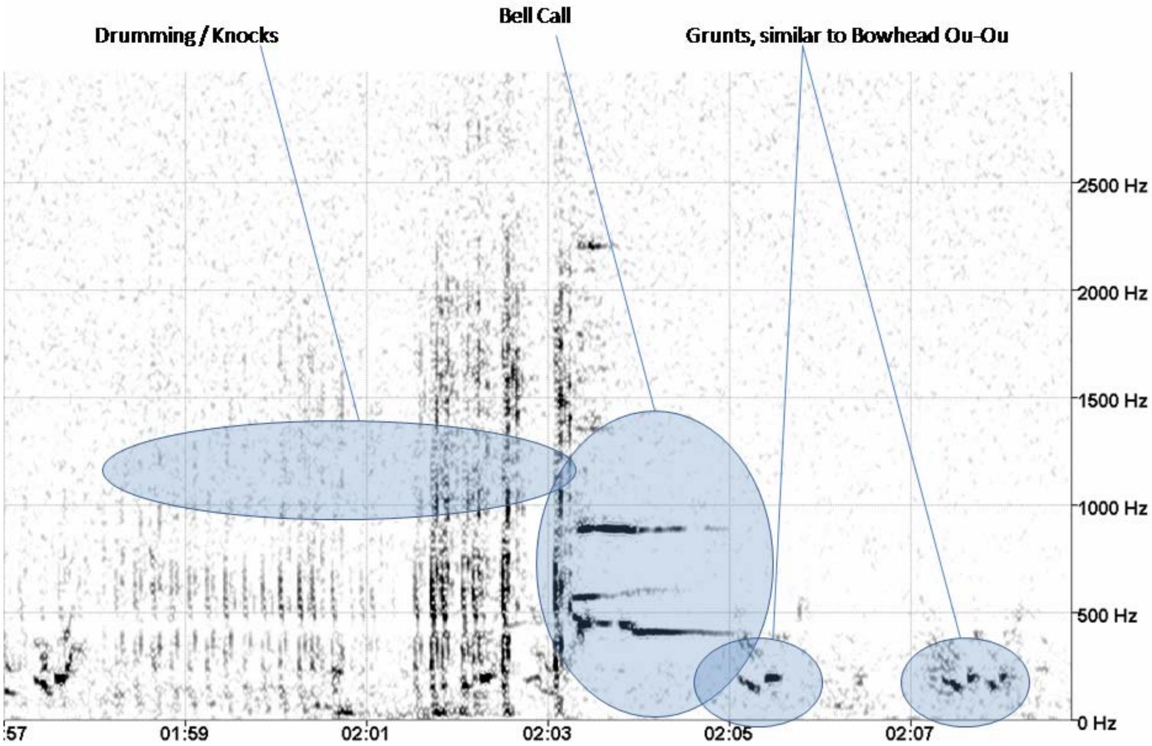

FIGURE 5.57. Example of three common walrus calls types: knocks, bell calls, and grunts. From OBH B35, file BDCB0930 (FFTSize 16384, real samples 1024, overlap 768, normalized).

Detections at Barrow

Figure 5.58 and Figure 5.59 show the walrus detections from the first and second deployments respectively. The following observations can be drawn from these plots:

1. The level of activity increases with distance from shore.
2. There is evidence of two groups of walrus moving inshore along the Barrow line in early to mid Aug. The first group appears to move inland on the 10 -12 Aug, and the second group on the 12-13 Aug.
3. The walruses appear to have departed the Barrow area 07-08 Sep.
4. There is minimal activity during the second deployment (11 Sep – 25 Oct).

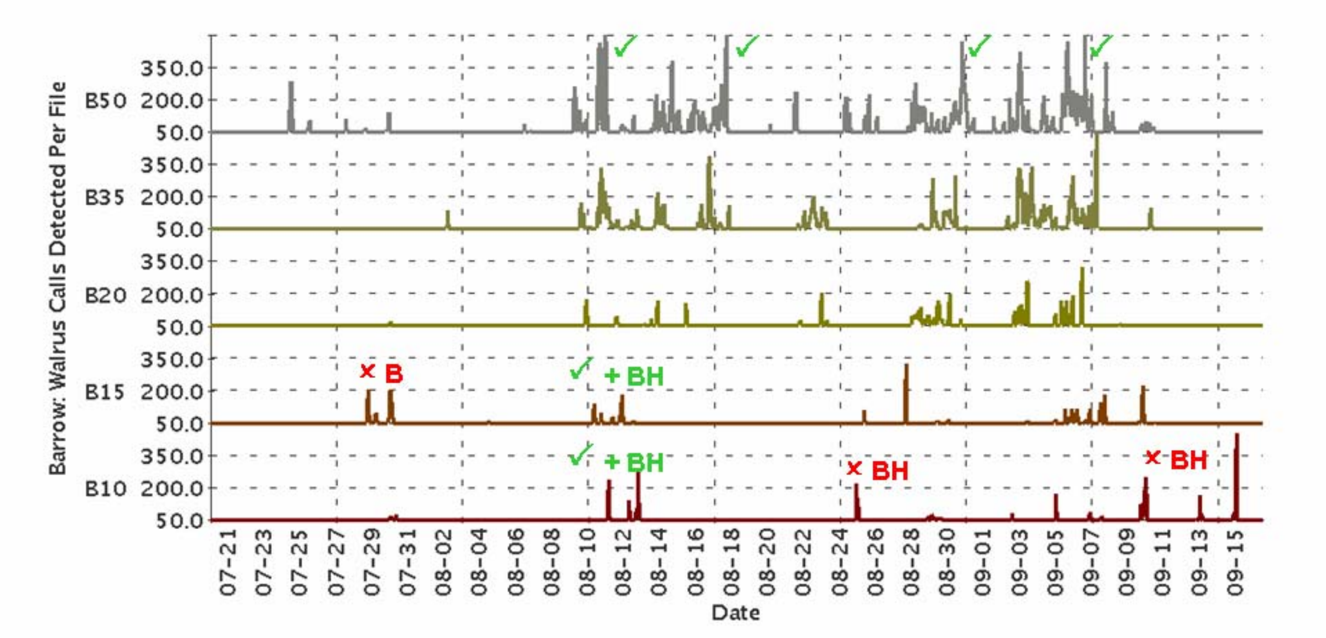

FIGURE 5.58. Number of walrus calls per file, Barrow line, first deployment. Check marks are detections that have been manually validated; bowheads are also present if there is a '+BH". Peaks with a red 'X BH' indicate that the peaks were only bowhead calls without walrus. Peaks with a red 'X B' indicate that the peaks were actually beluga calls.

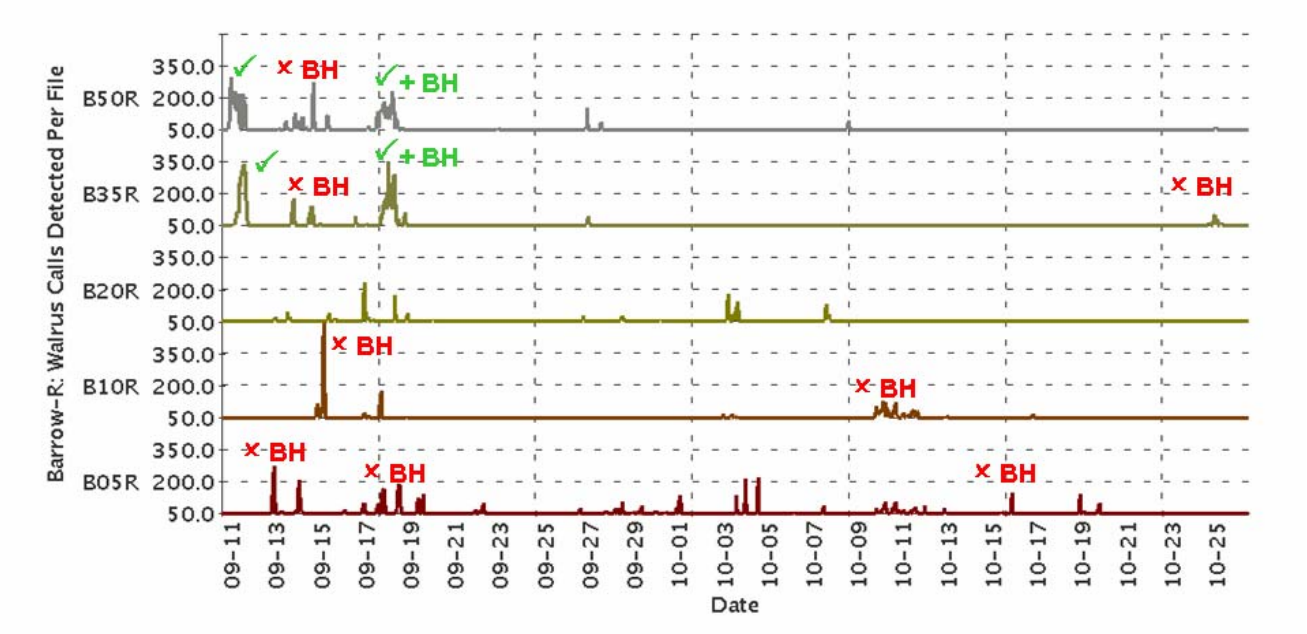

FIGURE 5.59. Number of walrus calls per file, Barrow line, second deployment. Check marks are detections that have been manually validated; bowheads are also present if there is a '+BH". Peaks with a red 'X BH' indicate that the peaks were actually bowhead calls.

Detections at Wainwright

Figure 5.60 and document the walrus detections along the Wainwright Line during the first and second deployments respectively. The following can be noted:

1. There is generally more activity further offshore than inshore, with WN40 having nearly continuous activity throughout the first deployment.
2. There is some evidence of a move inshore between 7 and 9 Aug, followed by a move offshore on 15 and 16 Aug. This region is shown in Figure 5.61.
3. There is a very strong indication of movement inshore from W20 to W05 on 23 and 24 Aug. It appears the walrus traversed this 15 nautical mile span in 8 hours. They arrived at W20 at 16:30 on 23 Aug and at W05 at 02:00 on 24 Aug. A close-up of this time period is shown in Figure 5.62.
4. There are two more possible inshore movements shown, on 29 Aug and 11-12 Sep.
5. No obvious changes in spatial or temporal variations in call rates are apparent at the start of or during Shell's seismic activity from 29 Aug to 10 Sep.
6. The activity at W35 and WN40 early in the deployment correlates with the presence of sea ice near those sensors, see Figure 5.19. There is a strong possibility that the movement inshore was driven in part by the final dissipation of the ice in early Aug.
7. Walrus activity is much lower during the second deployment (14 Sep– 25 Oct).

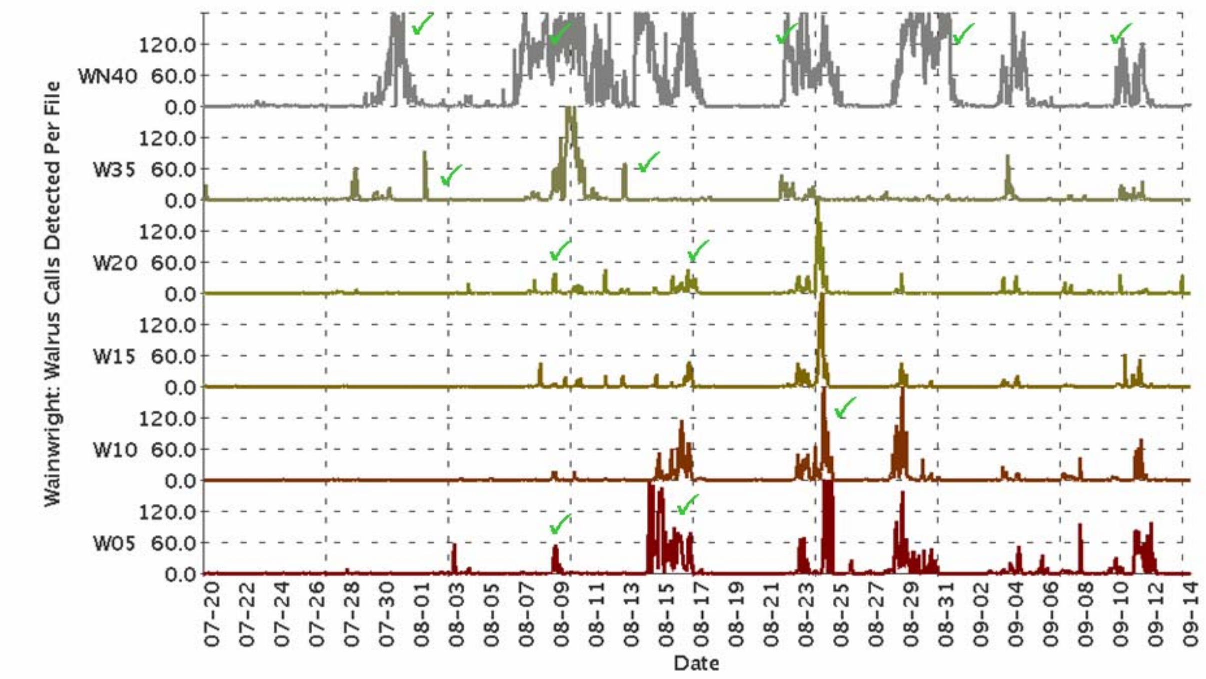

Figure 5.60. Walrus detections at the Wainwright line, first deployment.

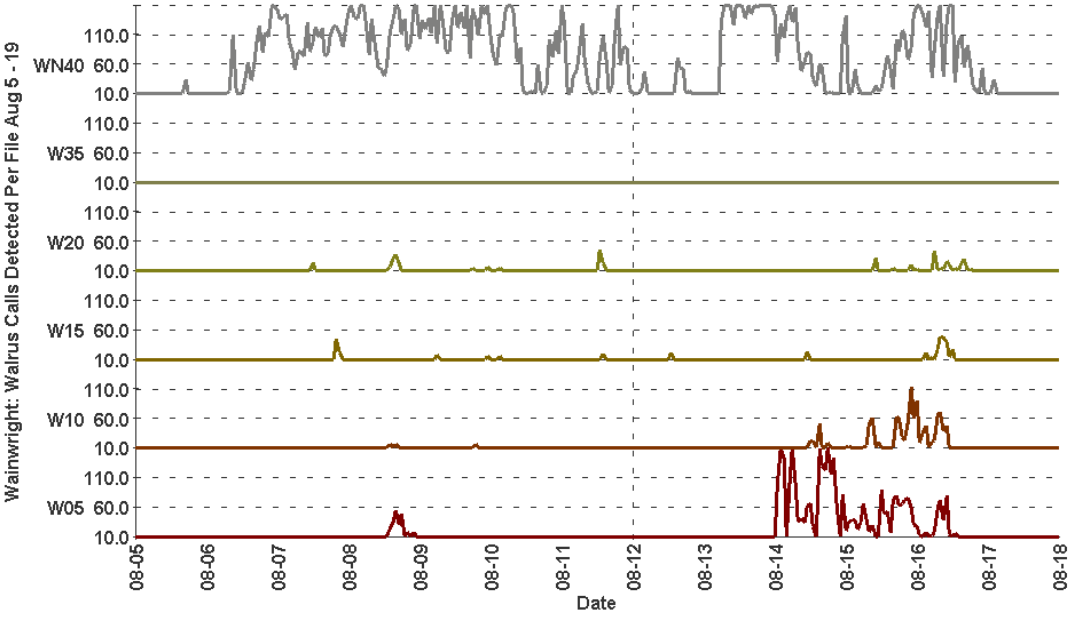

Figure 5.61. Inshore movement 7 – 9 Aug, with offshore movement 14 – 16 Aug.

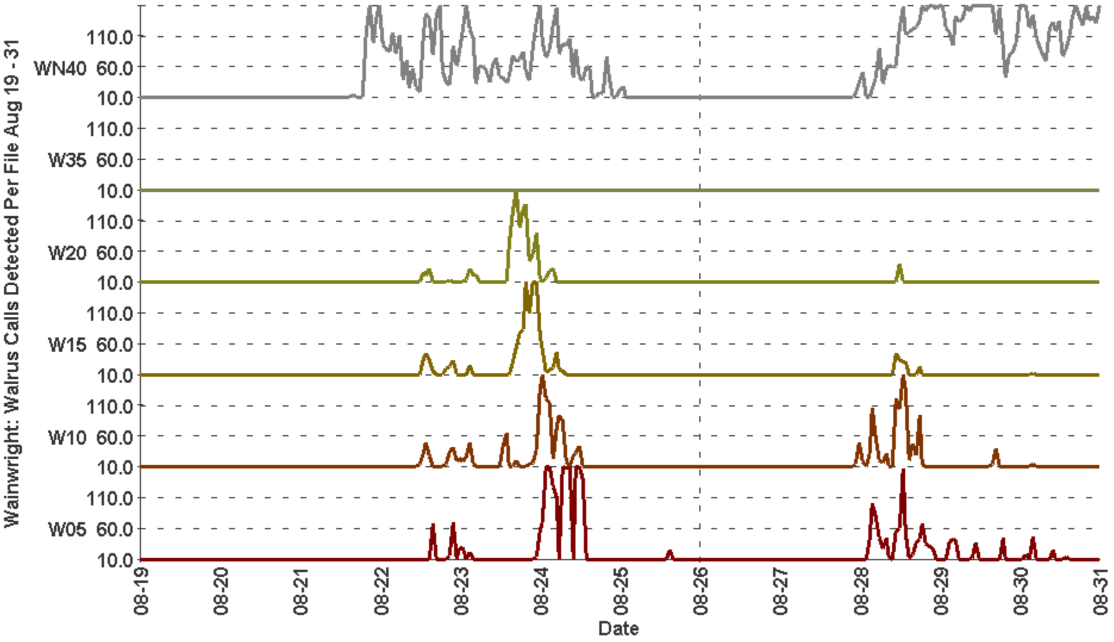

Figure 5.62. Zoom of the inshore movement, Wainwright line, 23 / 24 Aug.

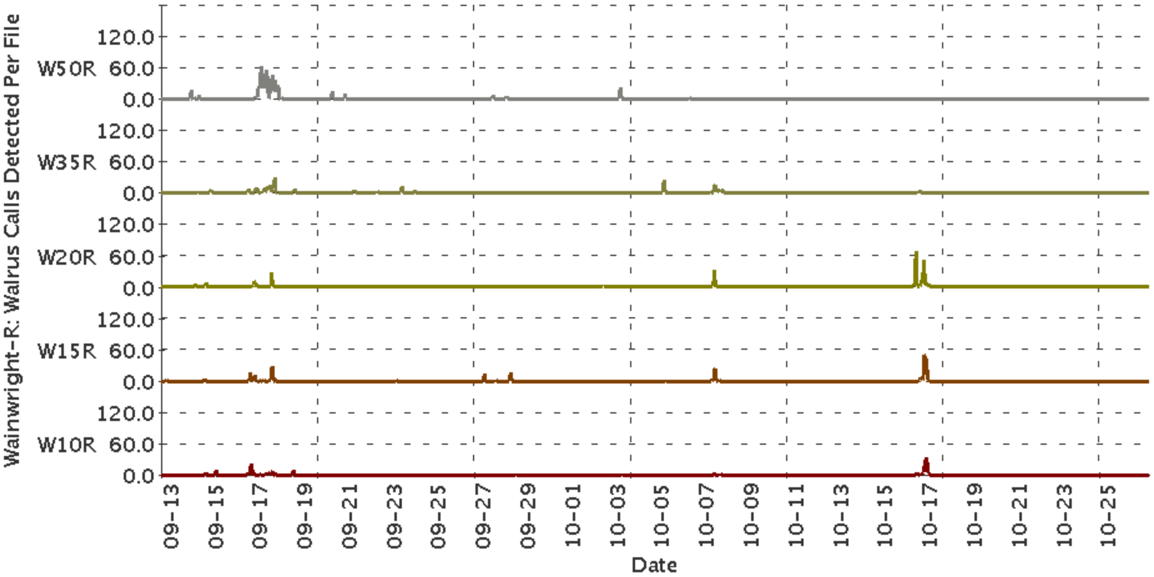

Figure 5.63. Walrus detections at the Wainwright line, second deployment.

Detections at Point Lay

The following observations can be made:

1. There is some level of activity on all OBHs throughout the first deployment.
2. There is a strong increase in activity near the inshore OBHs in mid Aug. There is evidence of a movement from offshore to inshore on the 14 – 16 Aug.
3. The sensors at 5 and 10 nautical miles from shore show near continuous activity after 15 Aug.
4. There is nearly continuous activity at PLN40 from 29 Aug to 14 Sep, that is over the period before, during, and after the main Shell seismic activity. A sample of walrus activity during the seismic events from PLN40 is shown in Figure 5.65.

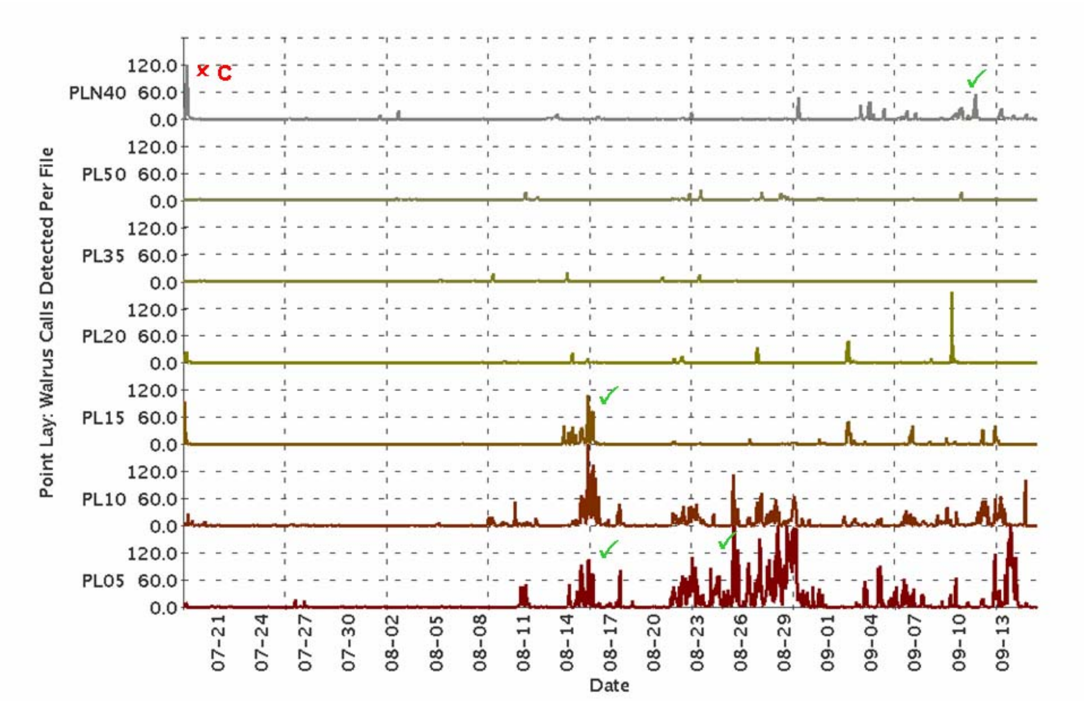

FIGURE 5.64. Walrus detections at the Point Lay line of sensors, first deployment. The event marked with a red ‘C’ we think may have been due to crustaceans on the hydrophone.

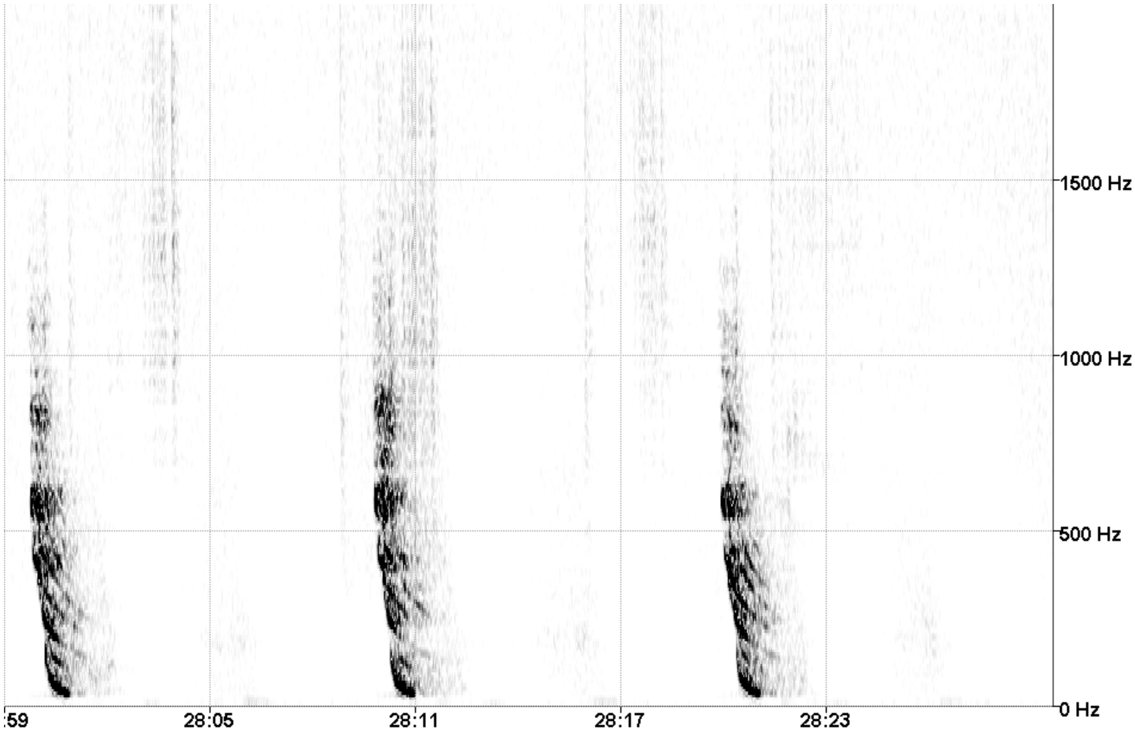

FIGURE 5.65. Walrus activity with seismic events, PLN40, File F8A71811. The shot SPLs for these events exceeded 120 dB (FFTSize 4096, real samples 1024, overlap 512, normalized).

Detections at Cape Lisburne

Figure 5.66 shows where the system detected walrus activity in the first deployment period around the Cape Lisburne OBHs. The following observations cam be made:

1. In general, the highest levels of activity are further offshore. Like Barrow, there is a surge in walrus activity in mid to late Aug.
2. There is often a mix of bowhead and walrus activity.

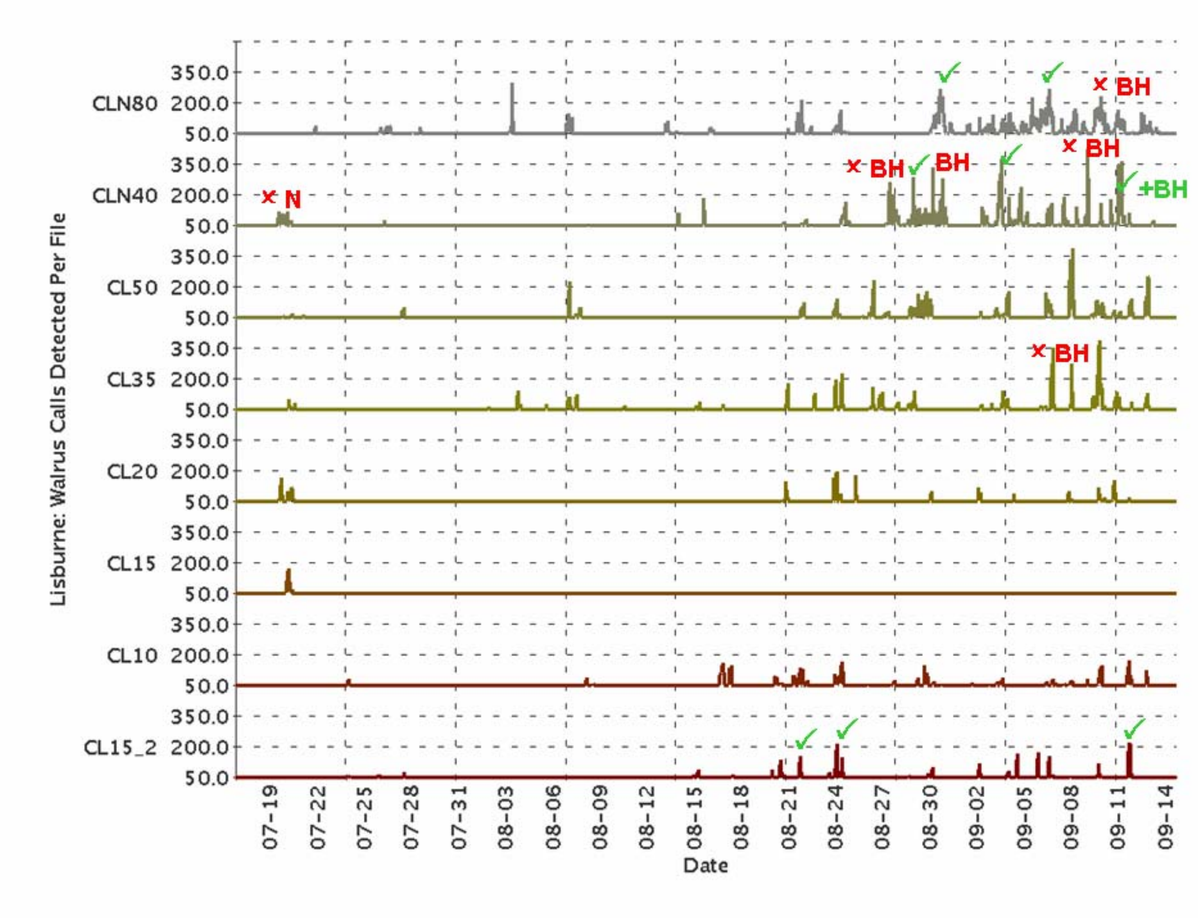

FIGURE 5.66. Walrus detections along the Cape Lisburne line, first deployment.

Summary

The data collected from the Chukchi net array allow the following observations to be made about walrus activities for the period of 17 Jul – 25 Oct 2007:

1. In general, more walrus vocal activity was observed at the OBH sites further offshore.
2. In early to mid Aug, some of the walrus appear to have moved inshore in groups. Their speed of advance was estimated at 1 to 2 knots. This pattern was noted on all OBH lines.
3. Following the inshore movement the walrus vocal activity around the inshore OBHs is at least as intense as the offshore OBHs.
4. In areas where seismic activity has been detected along with walrus activity, there is no apparent observations changes in walrus activity corresponding to the presence of seismic events.

Bubble plots of the walrus distributions were generated by adusting automatic detector/classifier results using adjustment factors determined through a process of manual validation This approach examined the weekly summed numbers of calls and accounted for walrus calls misclassified as bowheads. Those plots are shown in Figure 5.67 and Figure 5.68. Note the near continuous presence of large numbers of walrus near the Hanna Shoal at WN40.

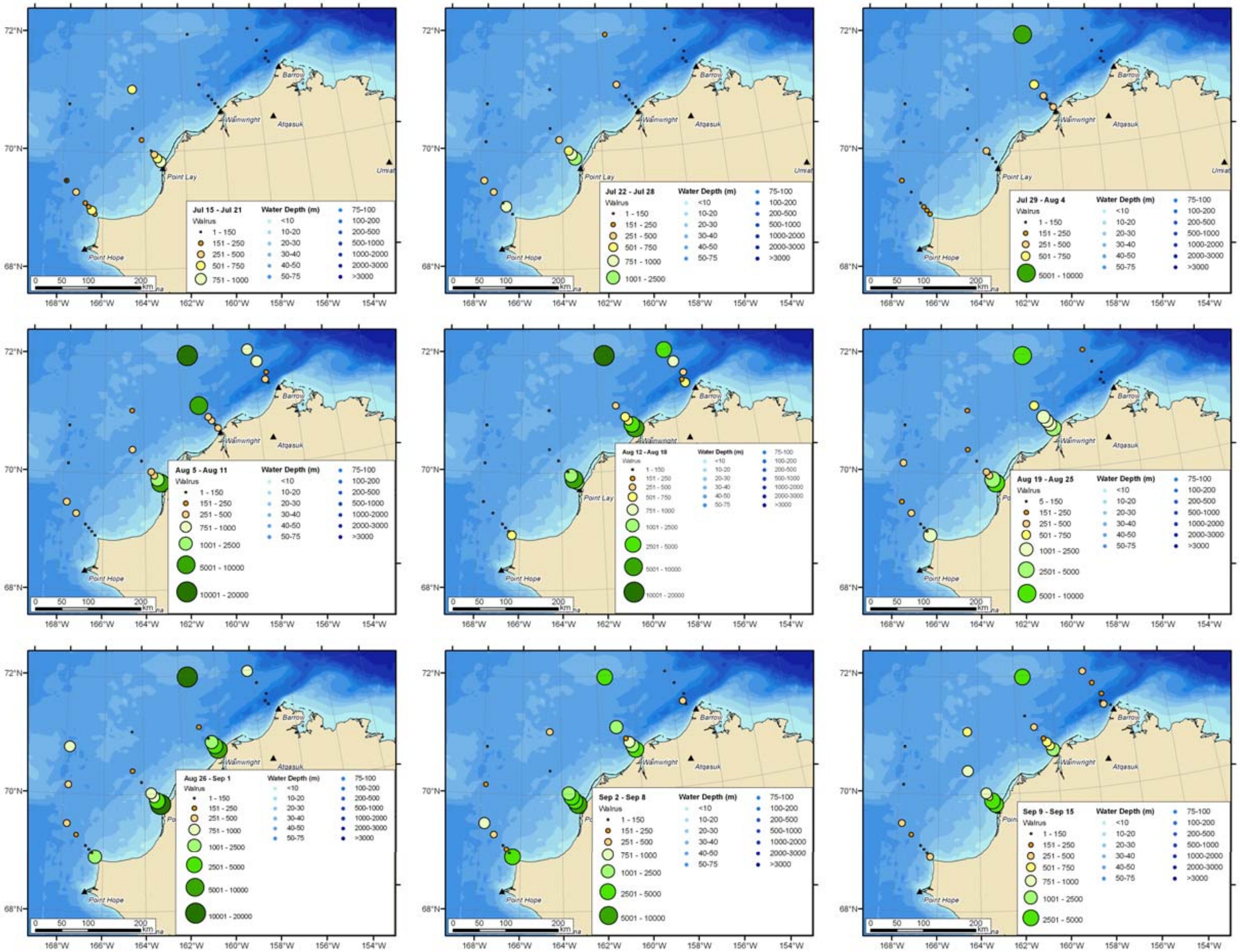

FIGURE 5.67: Weekly walrus distributions, after manual validation, first deployment.

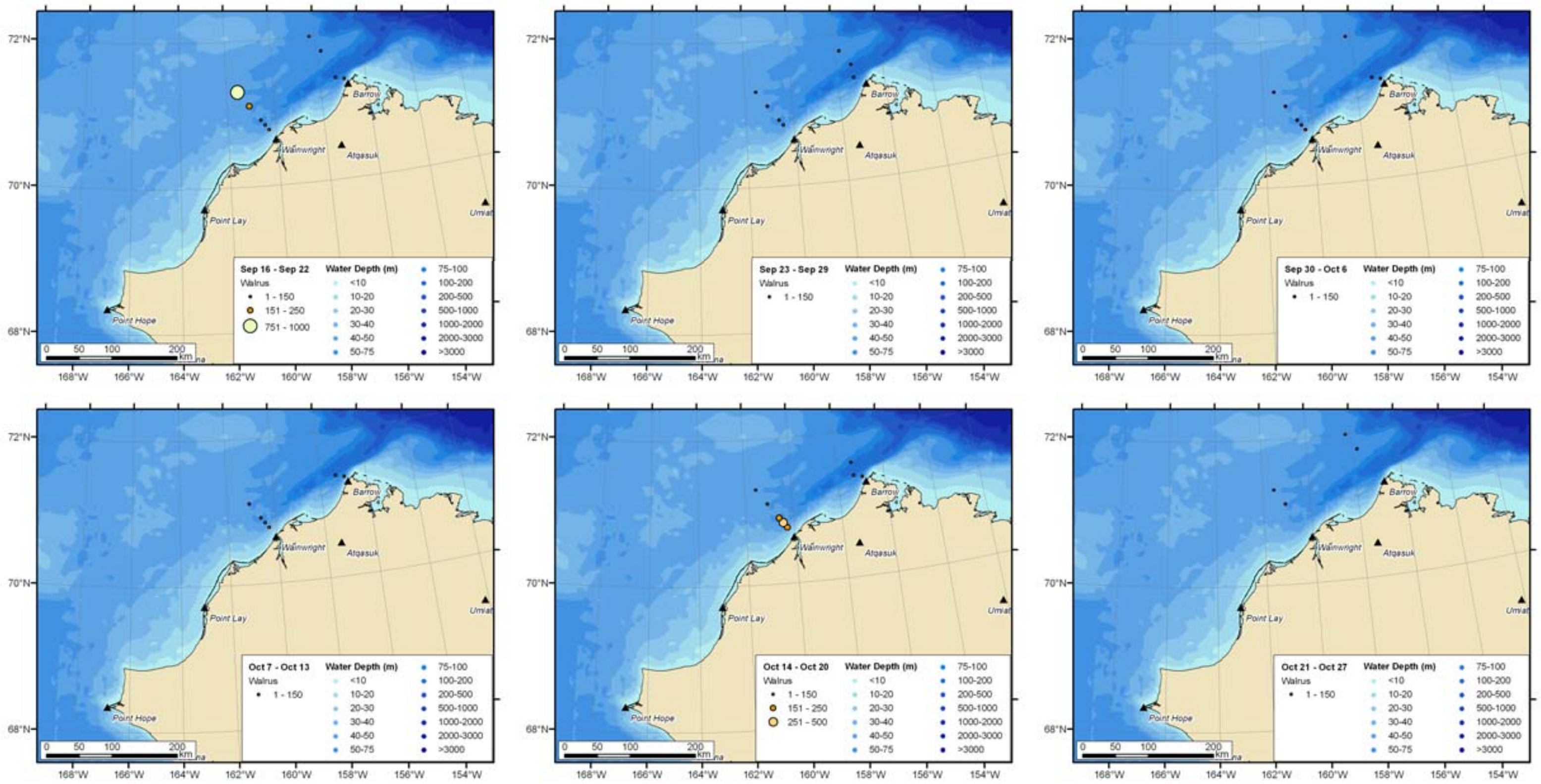

FIGURE 5.68: Weekly bowhead distributions, after manual validation, second deployment.

Phocidae (True Seals, Ice Seals)

Significant interest has arisen in the ability to detect seal distributions in the Chukchi using autonomous acoustic recorders. This interest was expressed late in the project and too late to incorporate automatic detection and classification of seal calls as was done for walrus, beluga and bowheads. Nevertheless, we performed a manual examination of the 2007 Chukchi OBH data for seal calls. We first conducted a literature review of the expected species and call types and then performed both a systematic and a random manual analysis of the data to search for seal vocalizations. The systematic analysis was conducted on all data from early in the monitoring program when the ice pack was still near the OBHs. The random analysis was introduced as an extension of the manual validation of the data that was performed to validate the automatic beluga, bowhead and walrus detections.

The species of interest are bearded, ribbon, ringed, and spotted seals. Recordings on the hydrophones near the ice began on 18 Jul 2007. Seals were likely on the ice at this time and may have been swimming and feeding near the OBHs. Seals, especially males, are more likely to vocalize under water during the breeding season from Apr to May, so very few seal sounds were expected during the deployment period. Very few known sound samples of any type of ice seal other than the bearded seal were available for comparison to our data.

Bearded seals (*Erignathus barbatus*) are circumpolar from the Bering Sea and Sea of Okhotsk up to 80ºN. They are usually associated with drifting sea ice in shallow waters. Male bearded seals are vocal during breeding season around mid-Apr when they begin underwater singing that can be heard from up to 20 km away. The song is a highly characteristic and complex frequency-modulated whistle, parts of which are audible to humans. They produce long downsweeping trills that can go from 5500 Hz down to 200 Hz and can be sustained for a minute. Trill source levels can be as high as 178 dB re 1 μPa-m. Vocalizations are expected to be less common outside of breeding season.

Ribbon seals (*Histriophoca fasciata*) are found in the offshore pack ice in southern Chukchi, Bering Sea and Sea of Okhotsk from Jan to May. They breed in water in the Bering and Okhotsk Seas. Some move north with the receding ice in summer but most are probably pelagic in unknown locations. Ribbon seals vocalize during the breeding season in May. Recordings made in the presence of ribbon seals in the northern Bering Sea made in May 1967 showed sporadic downsweeps and a broadband puffing sound (Watkins and Ray 1977). The downsweeps were separated into three categories: short (< 1 s, 2000-1750 Hz to 300 Hz), medium (1.3-1.8 s, 5300-2000 Hz to 1000 Hz), and long (4-4.7 s, 7100-3500 Hz to 2000 Hz). The short downsweep had a lower start and end frequency than the longer dowsweeps. The puffing sounds were just under 1 s long and broadband up to 5 kHz. Source levels of their sweeps are about 160 dB re 1 μPa-m.

Ringed seals (*Pusa hispida*) are circumpolar in the Arctic Ocean, Hudson Bay, Baltic Sea, and Bering Sea. They summer along the receding ice edge and further north in dense pack ice. They are largely solitary. They molt on the ice floes in Jun and Jul. Ringed seals emit several types of vocalizations underwater, especially during breeding season in late Apr to May. The function of these calls in unknown. One example is a repeated monkey like single barking sound slightly downsweeping at about 400 Hz. Sounds recorded in the eastern Canadian Arctic have been described as moans, whistles, descending chirps, barks, growls, grunts, and yelps (J. Terhune, pers. comm.; Figure 5.69). Stirling (1973) first described their calls as low-pitched yelps, barks, growls, and chirps. Their sounds are often faint and occurring in rapid succession. Yelps are usually high-pitched, ~1 kHz, and some are nasal sounding.

Barks are moderate to low frequency and short (0.2 s). Most of their sounds are below 5 kHz and have source levels of 95-130 dB re 1 μPa-m, and thus might only be heard 1 km away.

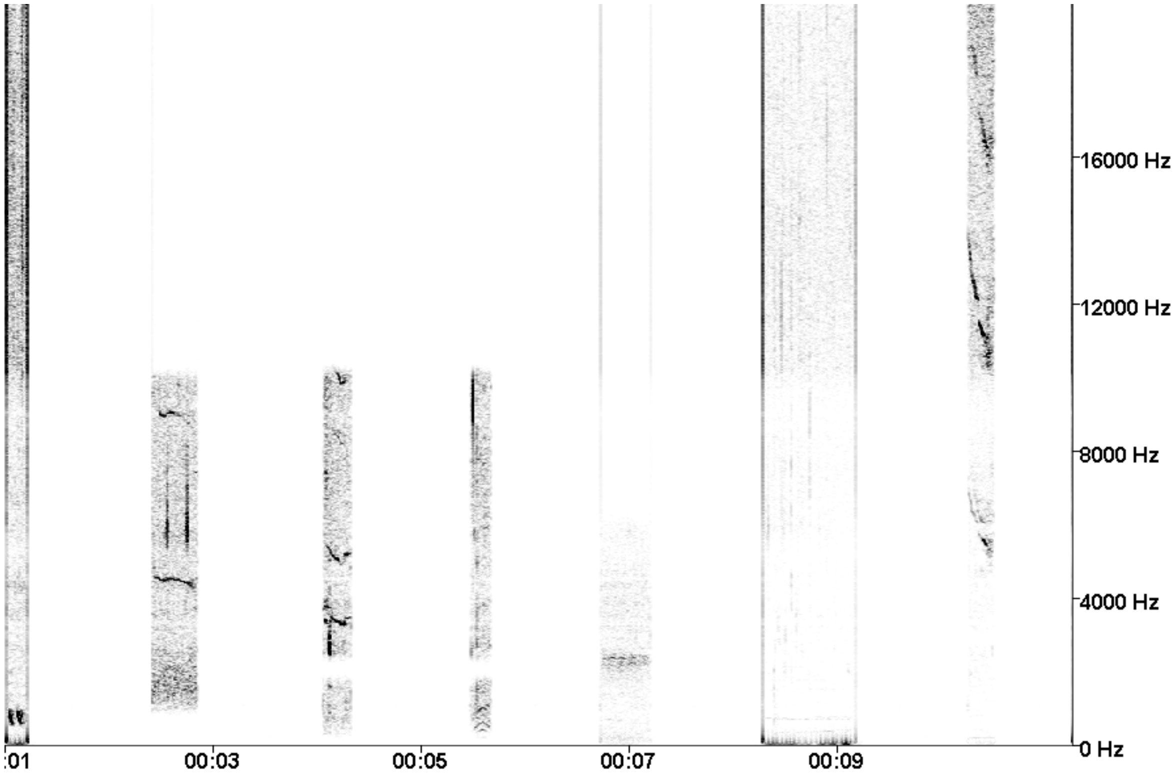

FIGURE 5.69: Ringed seal calls recorded in Repulse Bay, NU by the University of New Brunswick, Canada (sampled at 96 kHz, 64k FFT, 4096 real points with 1024 point advance).

Spotted seals (*Phoca largha*), also known as largha seals, occur in the North Pacific from the Sea of Okhotsk and Sea of Japan to the Bering Sea. They can also be seen along the Alaskan coast north to Bristol Bay and occasionally to the western Beaufort. They haul out and breed on pack ice, sometimes sandbars and gravel beaches, from Jan to mid-Apr. They spend spring and summer in the open ocean. Little is known about their behaviour or vocalizations because pack ice is difficult to access. Spotted seals do not seem to be especially vocal except when in molting groups on the ice between spring and autumn. When encountered in such groups, they make a variety of sounds describable as growls, barks, moans, and roars.

Detections of Bearded Seals

A few recordings of trill like sounds were found that could have been made by bearded seals. They are shorter in duration than a known recording from Cornell University's sound library (ref. Figure 5.70), but this could be due to temporal changes in call structure. The recordings from Cornell's site were made earlier in the year, during breeding season. Below are a few examples of potential bearded seal trills from various recorders and days (Figure 5.71 to Figure 5.74).

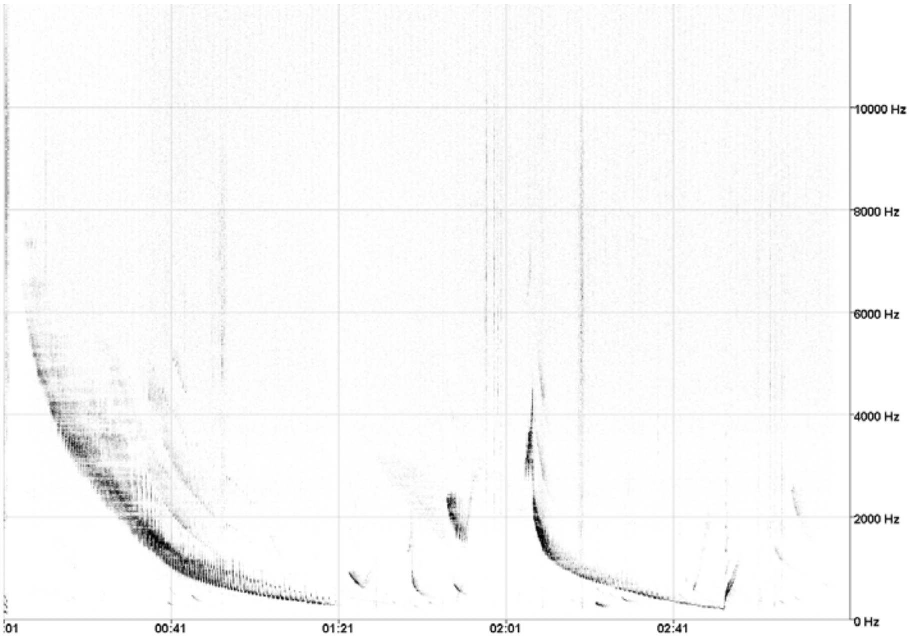

FIGURE 5.70: Bearded seal recorded in spring off Point Barrow by Cornell University (48 kHz sampling, 16384 point FFT, 4096 real points, 1024 point advance).

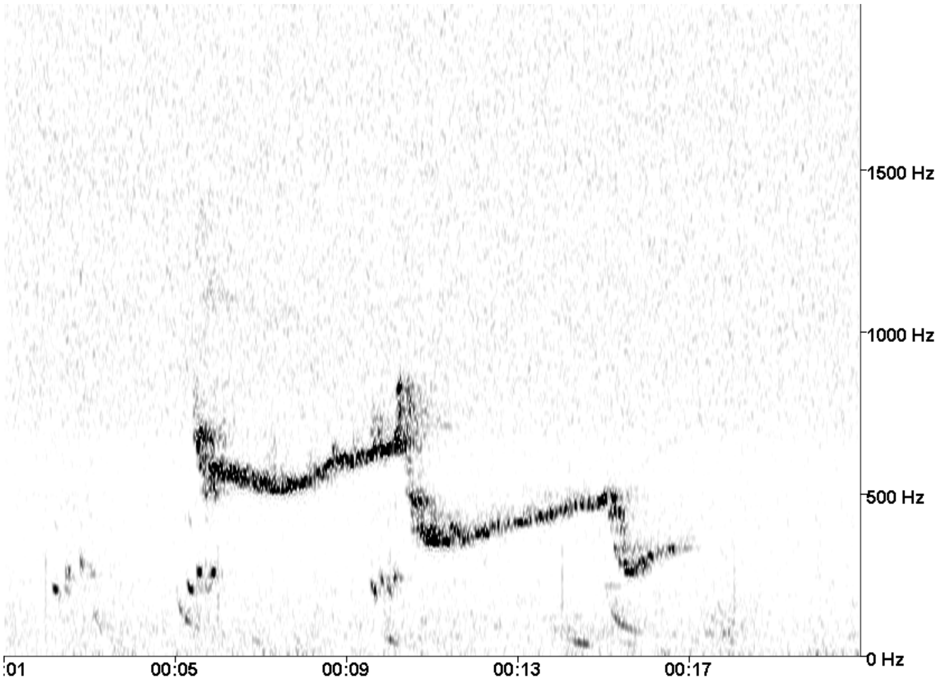

FIGURE 5.71: Possible bearded seal short trill at B35, 30 Aug 2007 01:23 (16384 Hz sampling rate, 16384 point FFT, 1024 real points, 256 point advance).

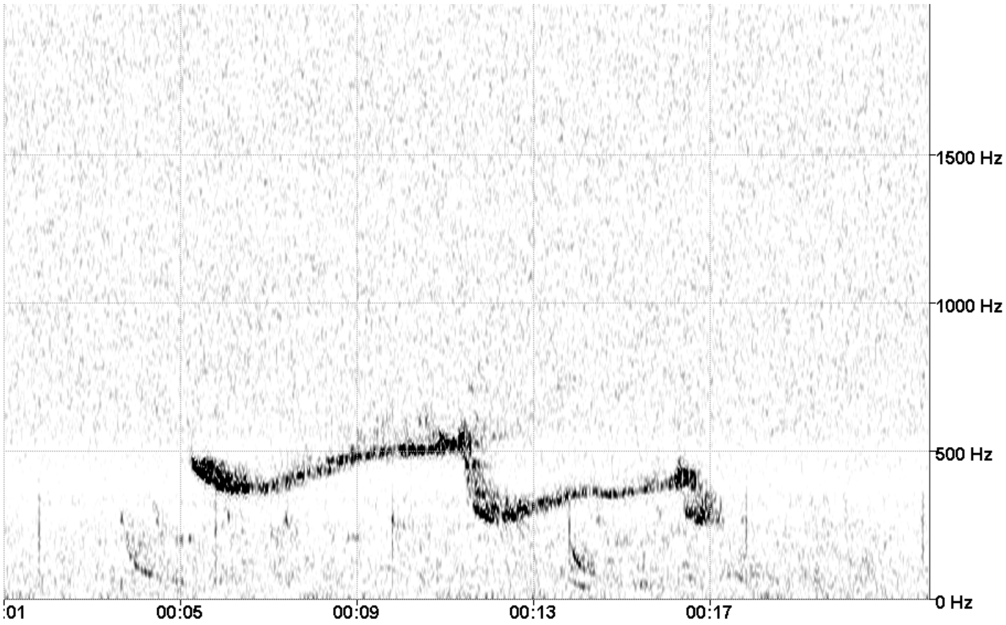

FIGURE 5.72: Possible bearded seal short trill at B35, 30 Aug 2007 01:31 (16384 Hz sampling rate, 16384 point FFT, 1024 real points, 256 point advance).

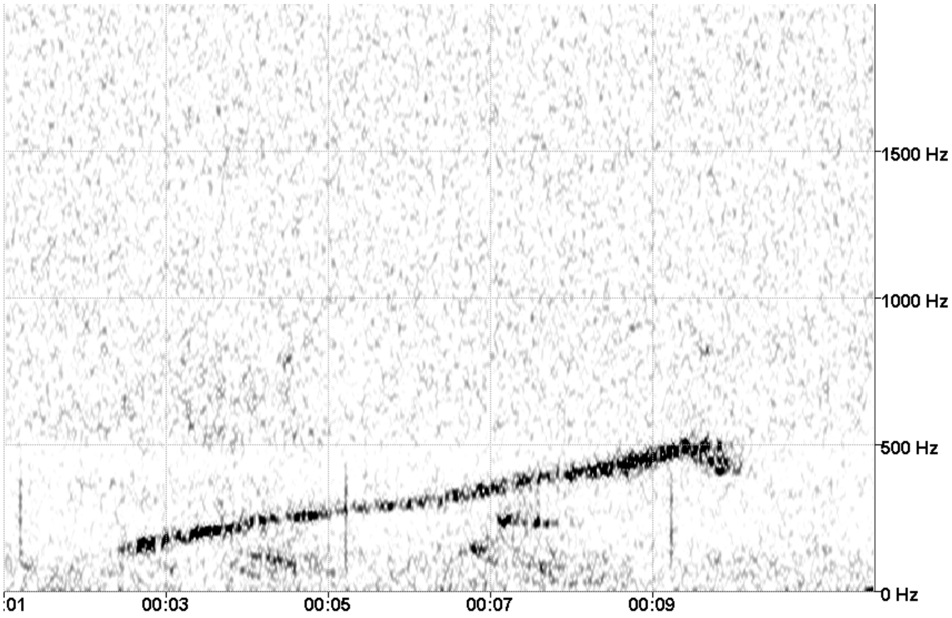

FIGURE 5.73: Possible bearded seal short trill at B35, 30 Aug 2007 01:40 (16384 Hz sampling rate, 16384 point FFT, 1024 real points, 256 point advance).

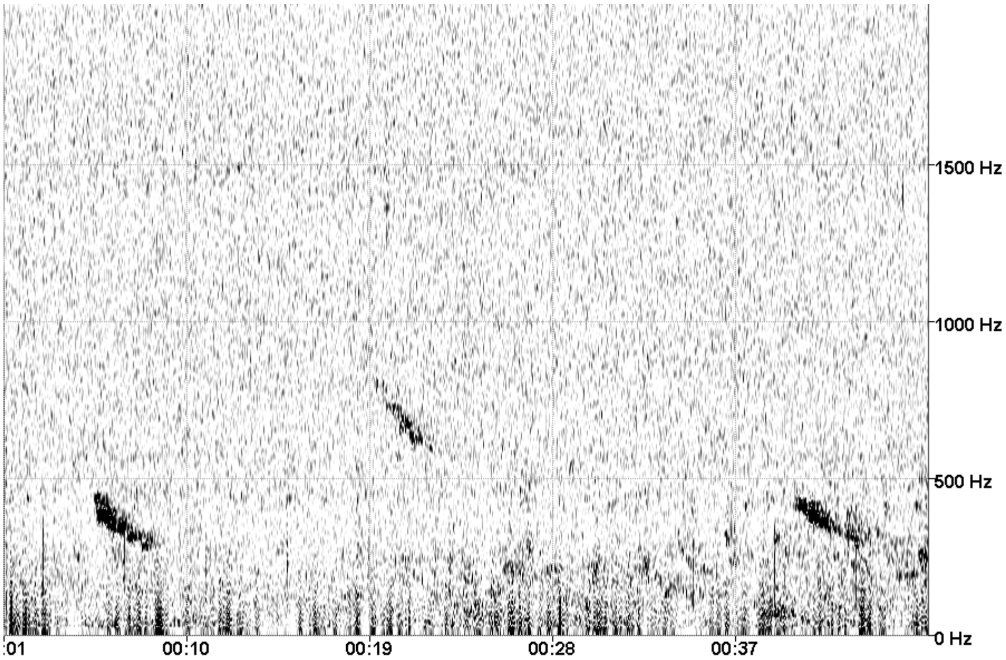

FIGURE 5.74: Possible bearded seal short trills at B10 Aug 29, 2007 04:50(16384 Hz sampling rate, 16384 point FFT, 1024 real points, 256 point advance).

The recording in Figure 5.75 was made at W35R on Oct 23, 2007 at 21:50. It included sounds presumed to be from bearded seals and bowheads, as well as airgun shots. The long downsweeping sounds are seal calls. The vertical equally spaced sounds are airguns. The other sounds are likely bowheads, although some of those could also be seals.

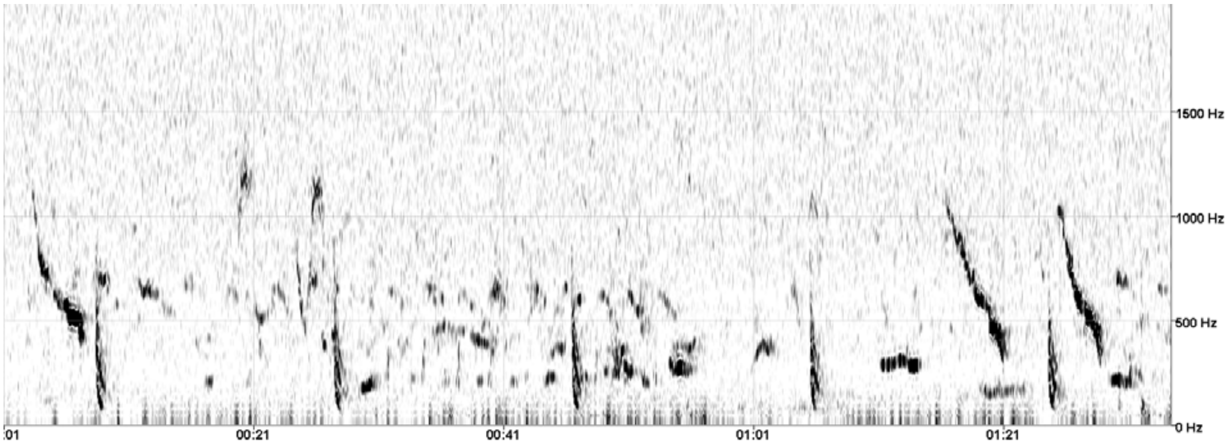

FIGURE 5.75: Bearded seals, airguns, and bowheads at W35R, 23 Oct 2007 21:50 (16384 Hz sampling rate, 16384 point FFT, 512 real points, 256 point advance).

Detections of Ribbon Seals

Recordings in the presence of ribbon seals in the northern Bering Sea made in May 1967 (Watkins and Ray, 1977) included 1.5 s downsweeps (Figure 5.76).

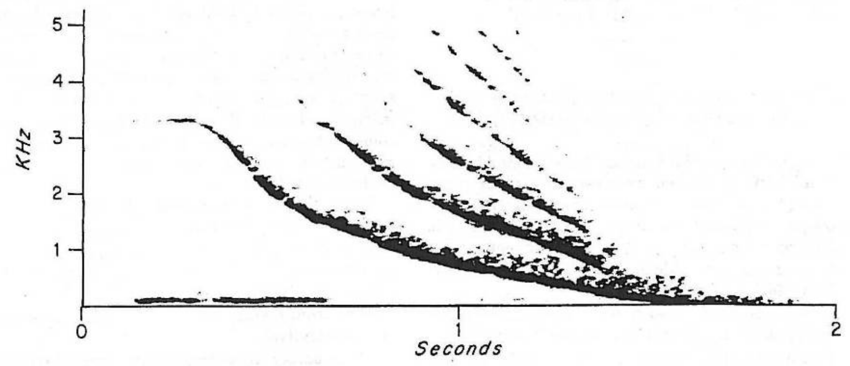

FIGURE 5.76: Example of a medium length downsweep of a ribbon seal. (from Watkins and Ray, 1977)

The sound in Figure 5.77 was recorded at W35 on 22 Jul, 10:15. It was only about 0.4 s, sweeping from 3700 Hz to 1000 Hz. This call may be a short duration ribbon seal downsweep, but that cannot be confirmed. A call at CLN40, 19 Jul 2007 22:39 (Figure 5.78) may also be a ribbon seal or bearded seal call.

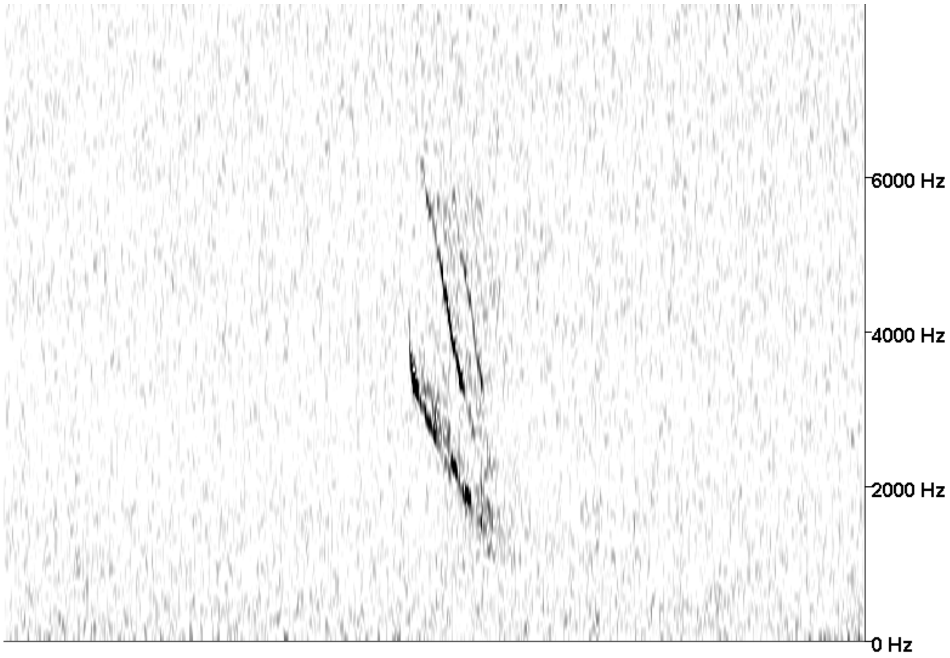

FIGURE 5.77: Possible 0.4 s ribbon seal call at W35, 10:15, 22 Jul 2007. (16384 Hz sampling rate, 16384 point FFT, 128 real points, 64 point advance). Note that the entire time shown is only 2 seconds.

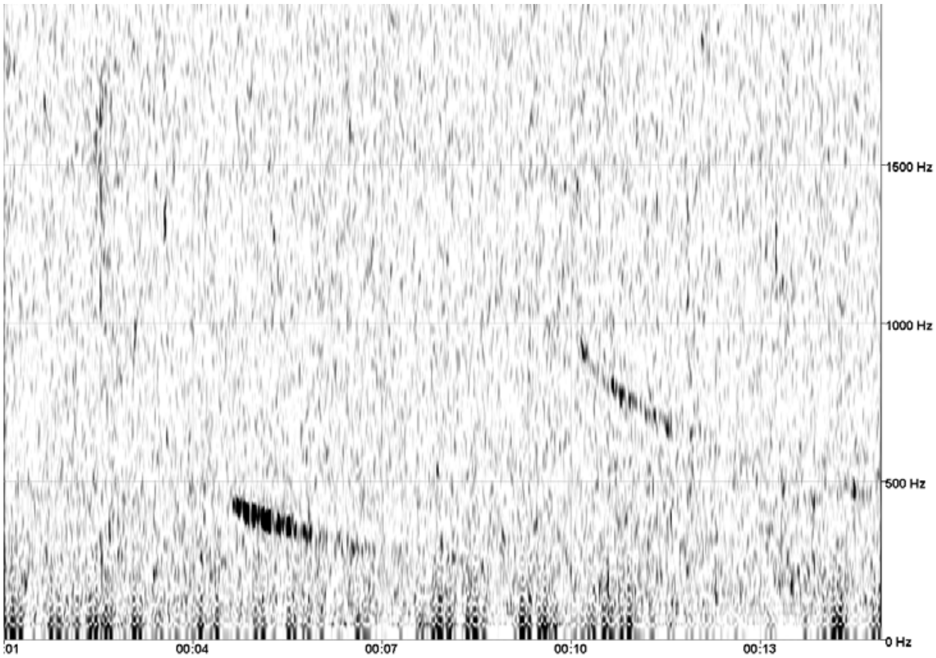

Figure 5.78: Possible ribbon or bearded seal at CLN80, 19 Jul 2007 (16384 Hz sampling rate, 16384 point FFT, 128 real points, 64 point advance).

Detections of Ringed Seals

Below is an example of ringed seal vocalization from Cornell University’s sound library recording “Ocean Voices of the Alaskan Arctic” (Figure 5.79). The 400 Hz barks are ringed seals. They are slightly downsweeping and have an intercall interval of about 0.25 s. The higher frequency wavy trills may be bearded seals.

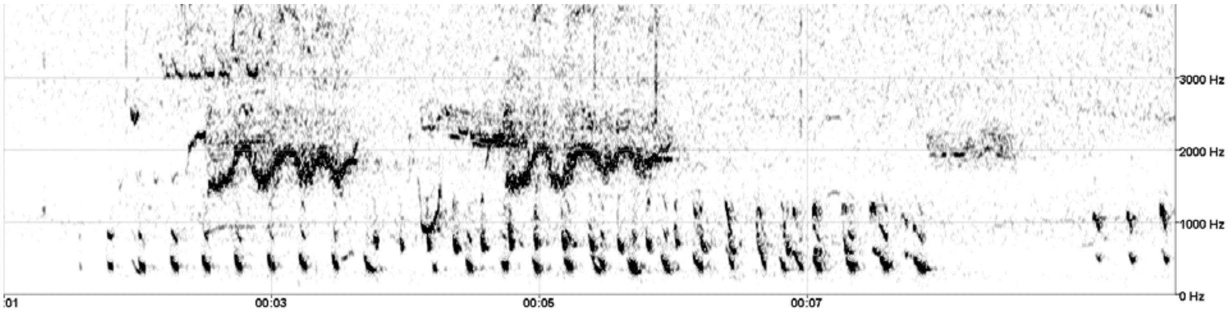

Figure 5.79: Ringed and Bearded Seals, From Cornell's Ocean Voices of the Alaskan Arctic (48 kHz sampling rate, 32768 pt FFT, 1024 real points, 256 point advance).

Figure 5.80 was recorded at station WN40 on 21 Jul 2007 at 13:28. The 430 Hz short barks with an intercall interval of 0.3 s were repeated several times and then again 15 s later. Figure 5.81 was recorded at WN40 on 22 Jul 2007 at 12:28. These could have been ice seal barks. They were at higher frequency and had different characteristics than the calls previously identified as walruses. These had an intercall interval of 0.37 s which was longer than expected and sounded different than the above ringed seal examples. Thus the species identification was unclear.

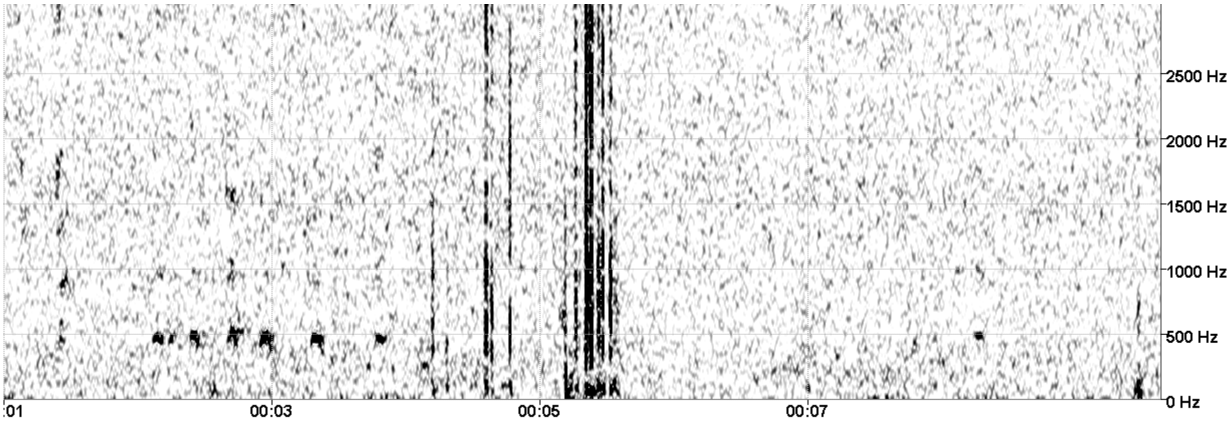

FIGURE 5.80: Possible ringed seal barks at WN40 21 Jul 07 13:28 (16384 point FFT, 512 real points, 128 advance). The intercall inverval is 0.3 seconds.

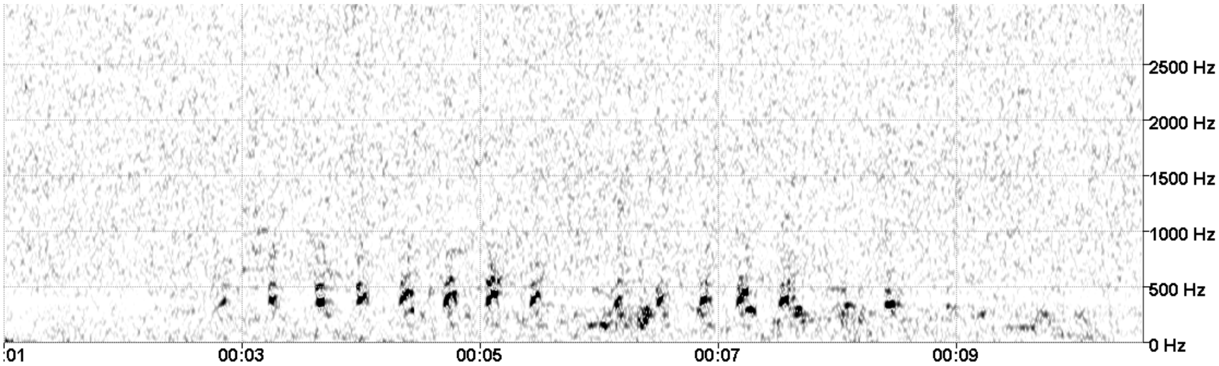

FIGURE 5.81: Possible ice seal barks at WN40 22 Jul 07 12:28 (16384 point FFT, 512 real points, 128 advance). The intercall inverval is 0.37 seconds.

Conclusions

Our background investigations on ice seal vocalizations indicated that these animals can be expected to have vocalized infrequently during the summer and early fall when the OBH recorders were deployed in 2007. The 2007-2008 over winter data can be expected to contain a higher probability of seal calls. *Note: the overwinter recorders do in fact show very large numbers of seal calls in Apr-Jun that will be discussed in the 2008 comprehensive report.* Only a small number of summer seal events were detected and reported here, however the manual examination for seal calls was limited. The use of the automatic classifier may provide better seal call identifications. The number of reference calls from other researchers and manually detected calls in the present data were insufficient as a basis for setting up an automatic classifier for these species at this time.

Additional Biological Signals Detected

The present analysis for detection of marine mammal vocalizations focused on the three species of most interest to the North Slope communities: beluga and bowhead whales as well as walrus. In the course of the study, various cases have been encountered where other calls have been misinterpreted by the automated classifier as one of the three species of interest. These have been manually removed from the results, pending improvements to the classifier to actively identify a broader set of signal types.

Many of the new signals that were encountered presented identification challenges for the internal team of biologists working on this project; in such cases outside experts were consulted to ensure that correct identifications were made.

The calls in Figure 5.82 have been identified as most likely coming from a humpback whale. These data were collected late in the season (18 Oct) at the easternmost sensor in this study, B05. That timing and location suggest that there could be humpback calls throughout the Chukchi OBH data as well as the DASAR data from a parallel study in the Beaufort. The improved classifier will be configured to discriminate for such calls, which would otherwise be identified as bowhead calls.

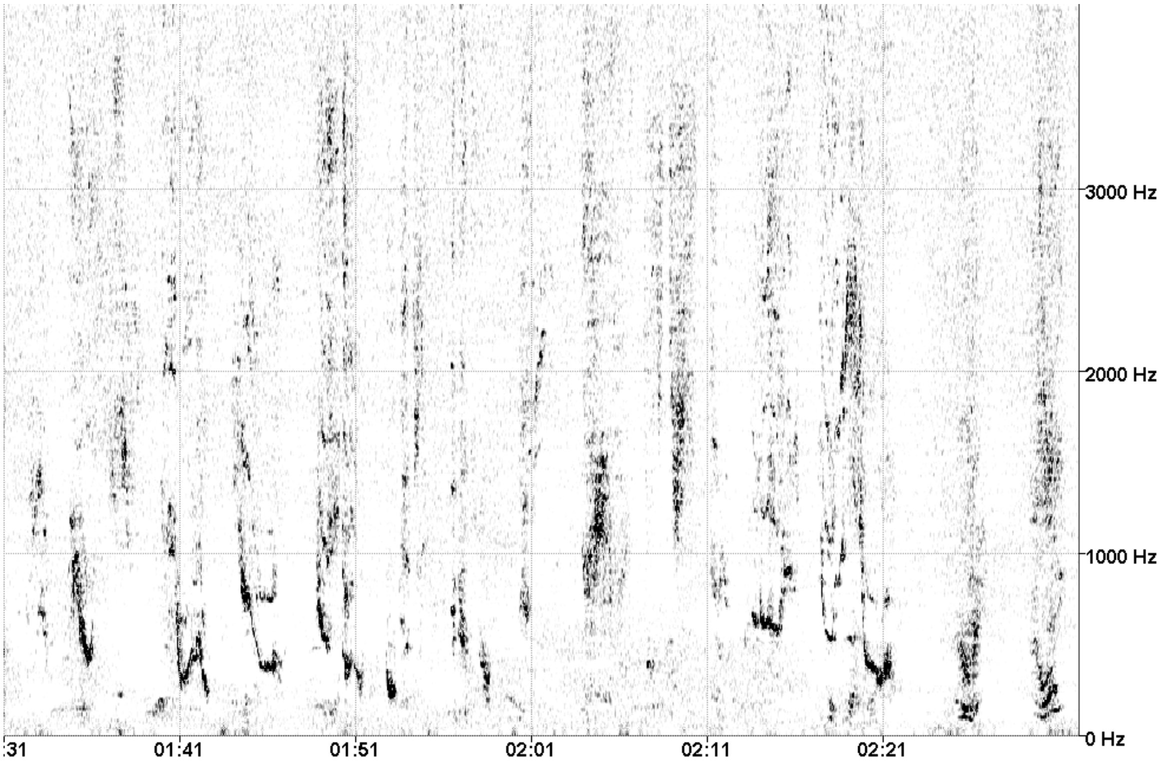

Figure 5.82. Sample humpback vocalization from B05R, File 367F1582, 22:40, 18 Oct 2007 (FFTSize 4096, real samples 1024, overlap 512, normalized).

Figure 5.83 shows a 1-minute spectrogram measured 18 Sep on B50 containing simultaneously both bowhead "ou-ou" calls and walrus knocks. The current classifier assumes that walruses are present when knocking is present but labels grunts as bowhead when no knocks are present. . The classifier successfully identified both walruses and bowheads in this data file because some "ou-ou" sounds occurred without knocks.

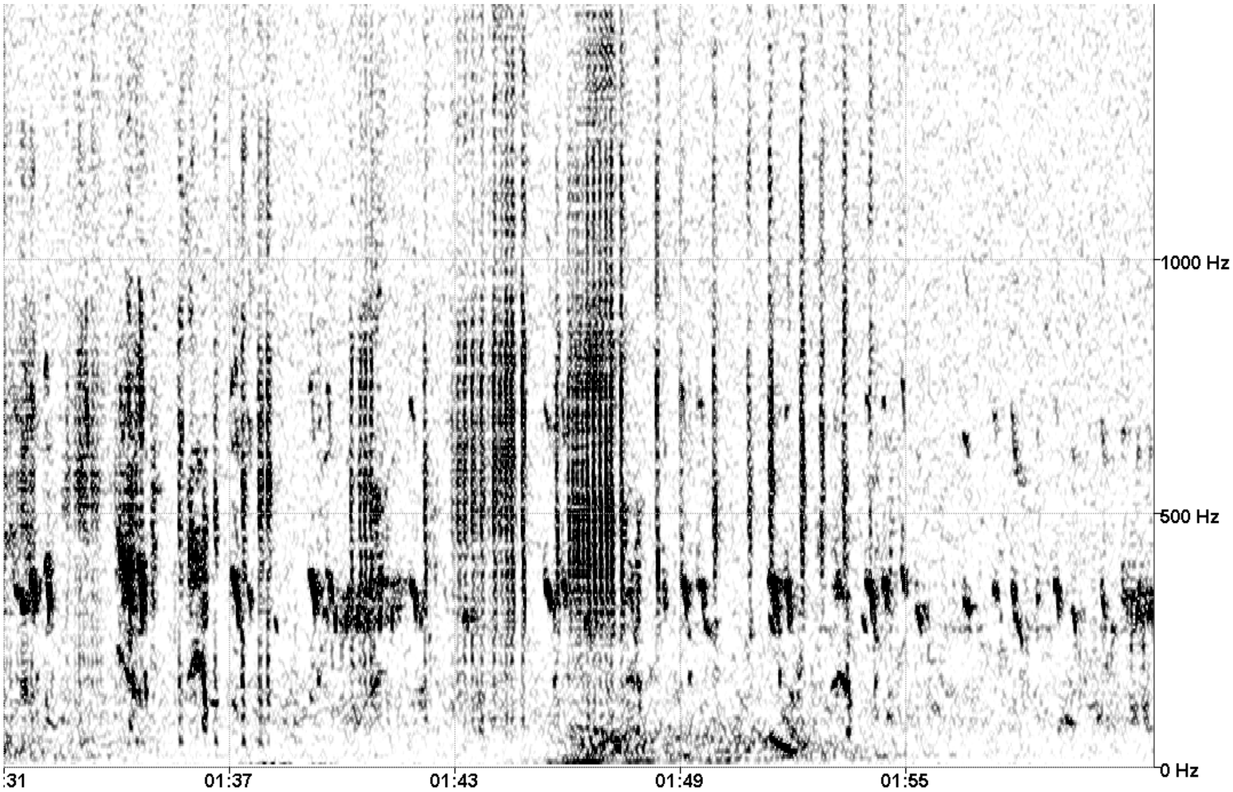

FIGURE 5.83. Walrus and bowhead calls, B50R, BDCB0317, 06:00, 18 Sep 2007 (FFTSize 4096, real samples 1024, overlap 512, normalized).

Figure 5.84 and Figure 5.85 show two very similar signals that the current classifier cannot distinguish. In both figures the time scale is very short, only fifteen seconds. Figure 5.85 is a typical walrus knock sequence with the amplitude and rate increasing, followed by a single slightly longer spaced knock. The vocalization in Figure 5.84 was misclassified as walrus; in fact it is from a gray whale and it is revealed to be such by the more random pattern of knocks. The identification as gray whale was confirmed by aerial survey data that showed gray whales near PL15 in late Jul, whereas walrus did not appear in the area until mid Aug.

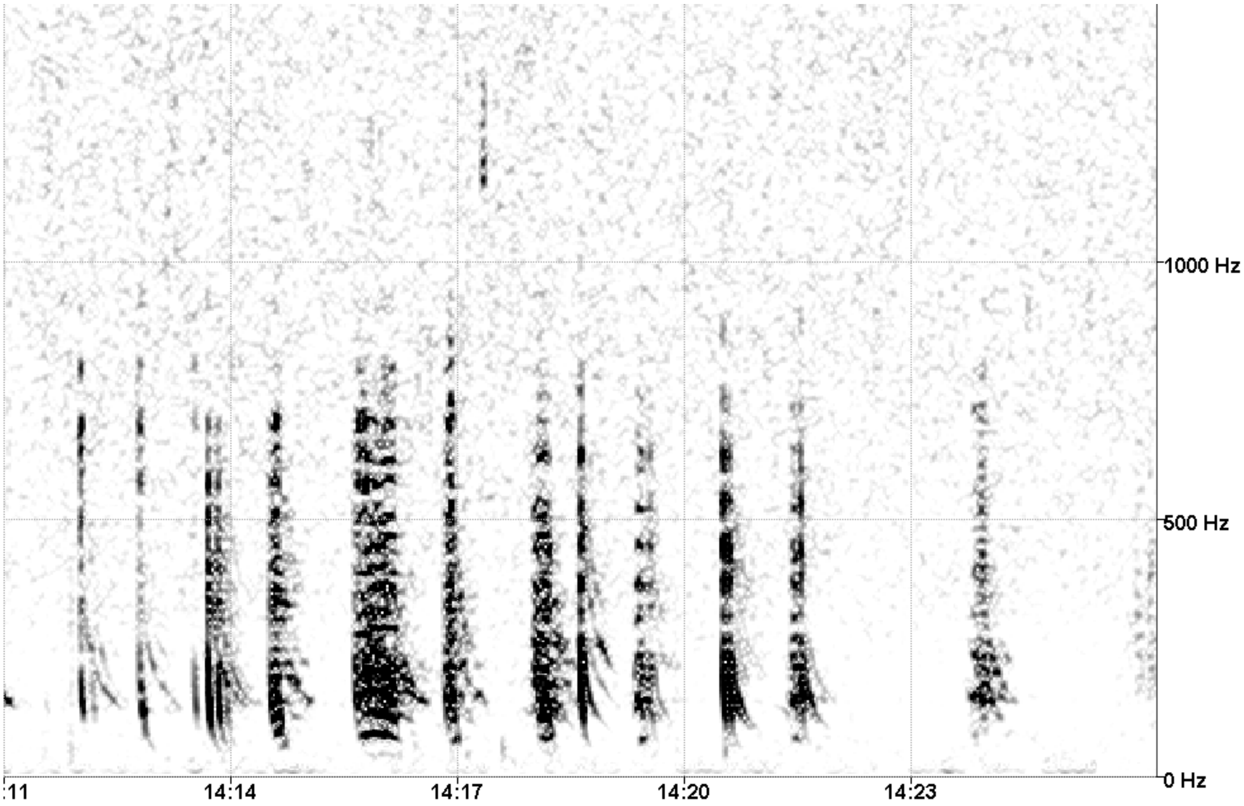

FIGURE 5.84. Gray whale knocks, PL15, 26 Jul 2007, File F8920323 (FFTSize 4096, real samples 1024, overlap 512, normalized).

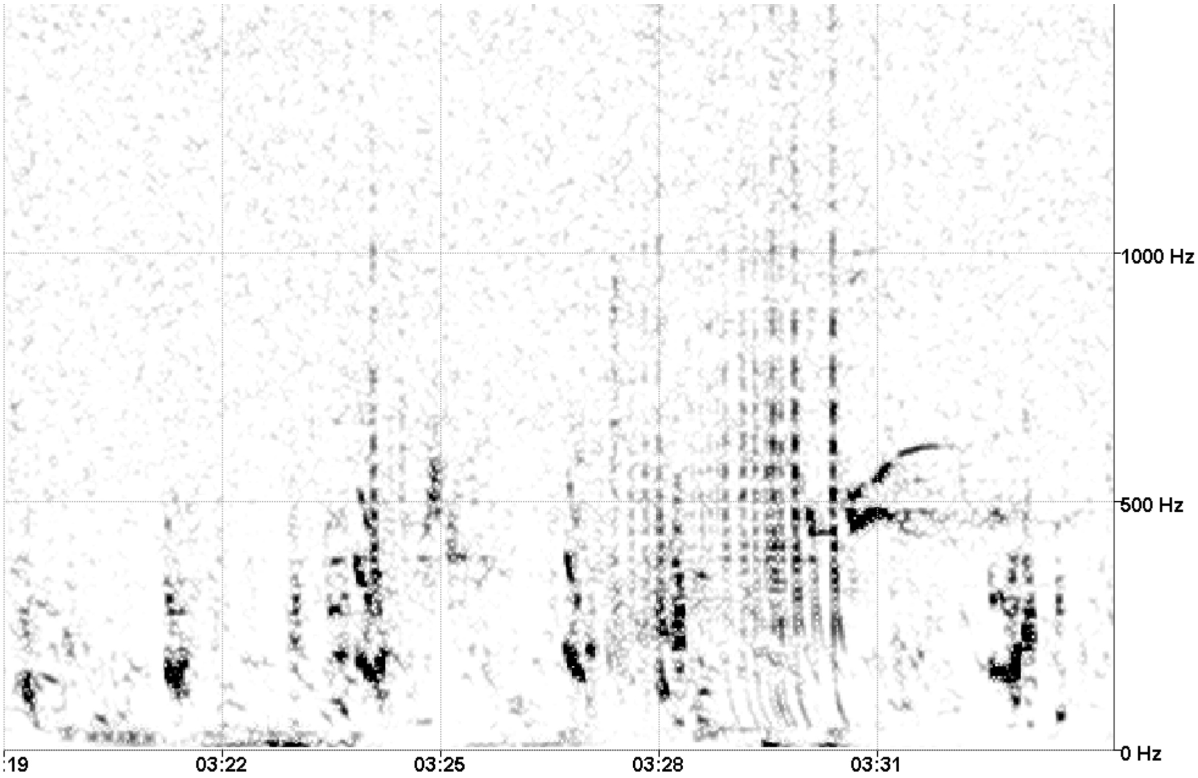

FIGURE 5.85. Walrus knocks, PL05, 28 Aug 2007, File 4FC21713 (FFTSize 4096, real samples 1024, overlap 512, normalized).

Figure 5.86 shows a very common type of event that is often misclassified as walrus knocks. This acoustic signal is caused by crustaceans, seals, fish, or other creatures touching the OBH hydrophone. The extremely wide bandwidth of these events can be used effectively to separate them into a different class even with the current processing structure; this additional discrimination however was not implemented within the timeline of the present study.

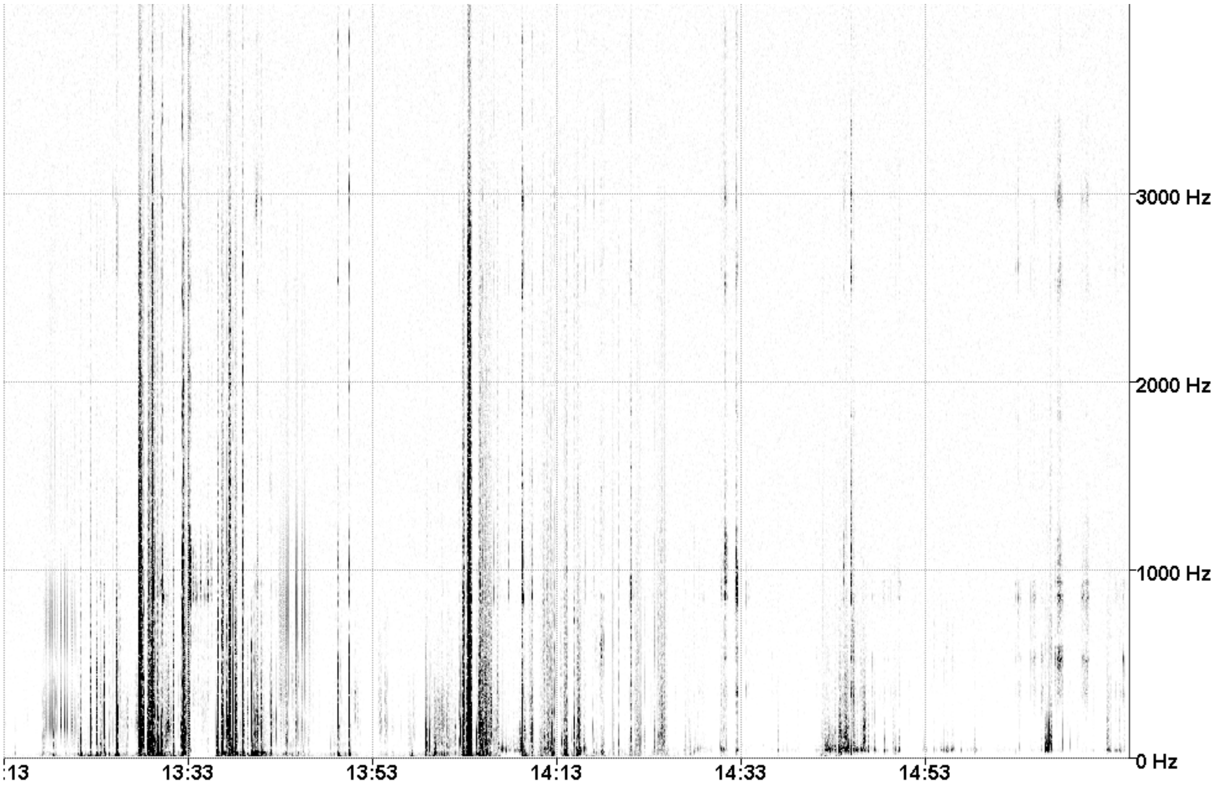

Figure 5.86. Biological activity touching hydrophone, A11-PLN40, 12:30, 2 Aug 07, file F8A70633. (FFTSize 4096, real samples 1024, overlap 512, normalized).

Figure 5.87 contains a very unusual call sequence that has not been identified. It resembles the sound a person might make by 'squirting' air through clenched teeth, followed by an "ou" sound very similar to a bowhead.

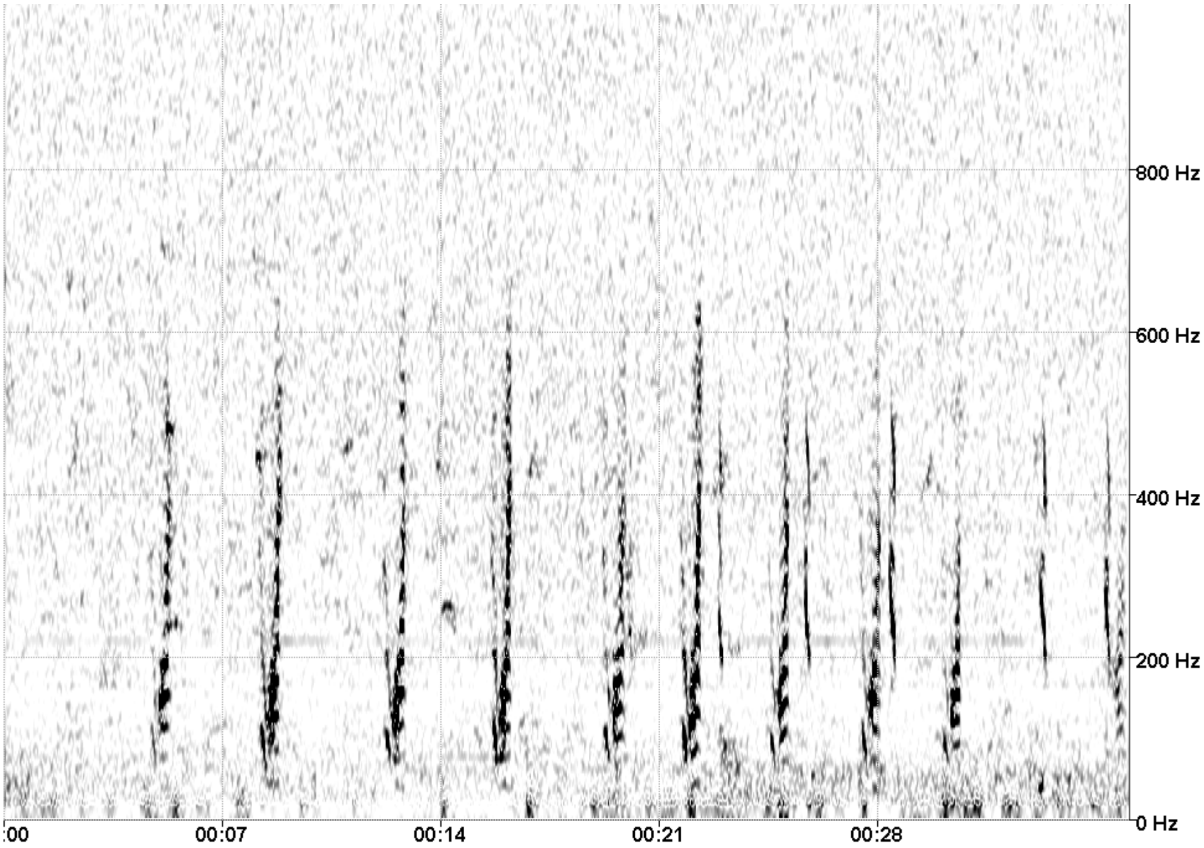

Figure 5.87. Unknown squirting and "ou" sequence, B15, File 00EA0907 (FFTSize 16384, real samples 1024, overlap 768, normalized).

Figure 5.88 is a call sequence that resembles a combination of a grunt and an "ou-ou". This sound has been reviewed by a number of people familiar with bowhead calls and it is not believed to be produced by a bowhead; its true nature is as yet undetermined.

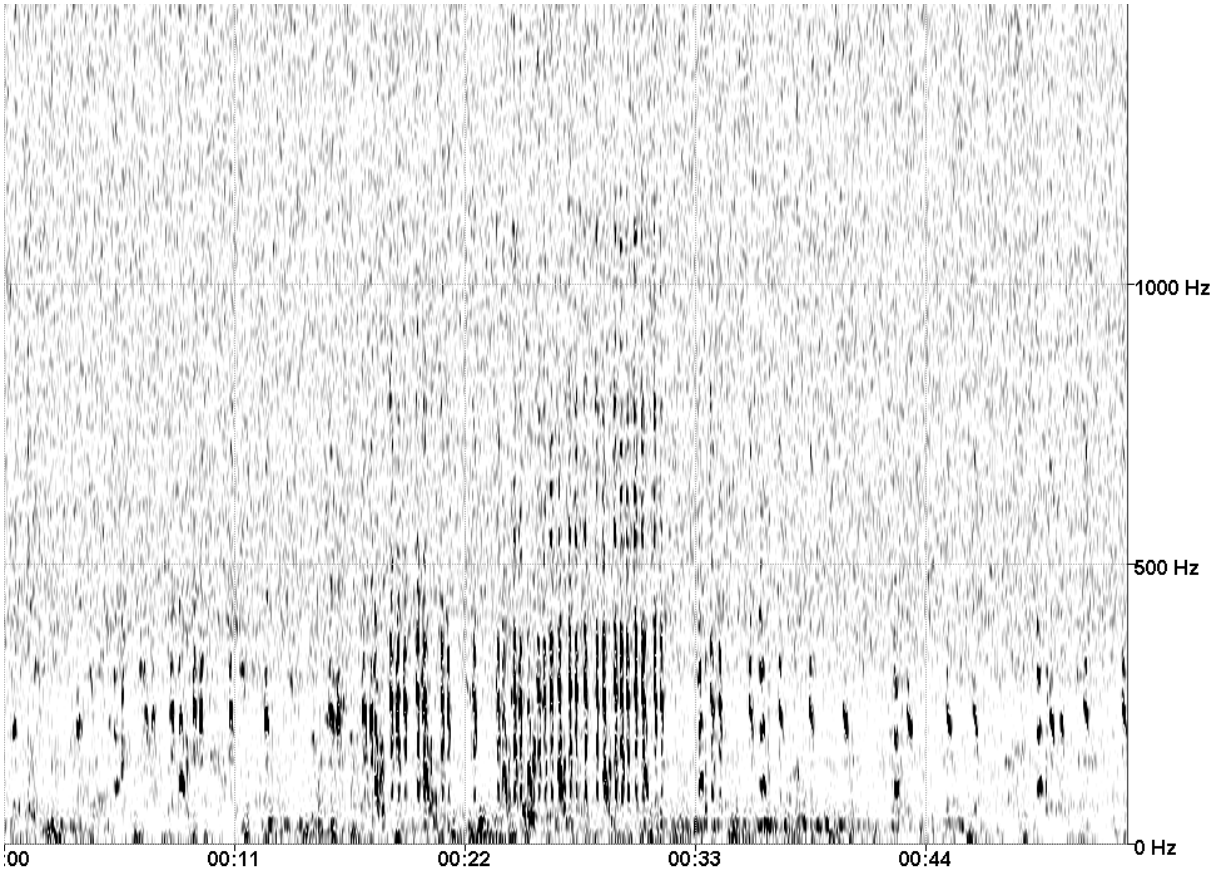

Figure 5.88. Vocalizations of unknown origin from W15, File 2A1B211. Some aspects are similar to the sounds identified as fish in the 2006 report by Cornell (FFTSize 16384, real samples 1024, overlap 512, normalized).

Narwhal (*Monodon monoceros*) clicks are narrow band pulses of nearly a single frequency up to 24 kHz (Watkins *et al.* 1971). The majority of clicks can be classified within two bands, 0.5 to 5 kHz and 12 to 24 kHz (Ford and Fisher 1978). Pulse repetition rates have been measured at 2 to greater than 500 per second. The click rates within a series tend to remain at the same repetition rate unlike for killer whales where the click rate tends to increase during echolocation (Watkins *et al*. 1971). The most common click rates in Ford and Fisher (1978) were 5 to 11 clicks/s and 30 to 140 clicks/s. Figure 5.89 shows two spectrograms of narrow frequency band clicks with repetition rates of about 15 to 60 clicks/s. These sounds were received at B10 on 10 Aug 2007. The frequency bands and repetition rates correspond to those described above for narwhals. The second spectrogram also includes a whistle. The literature reviewed did not describe narwhal whistles.

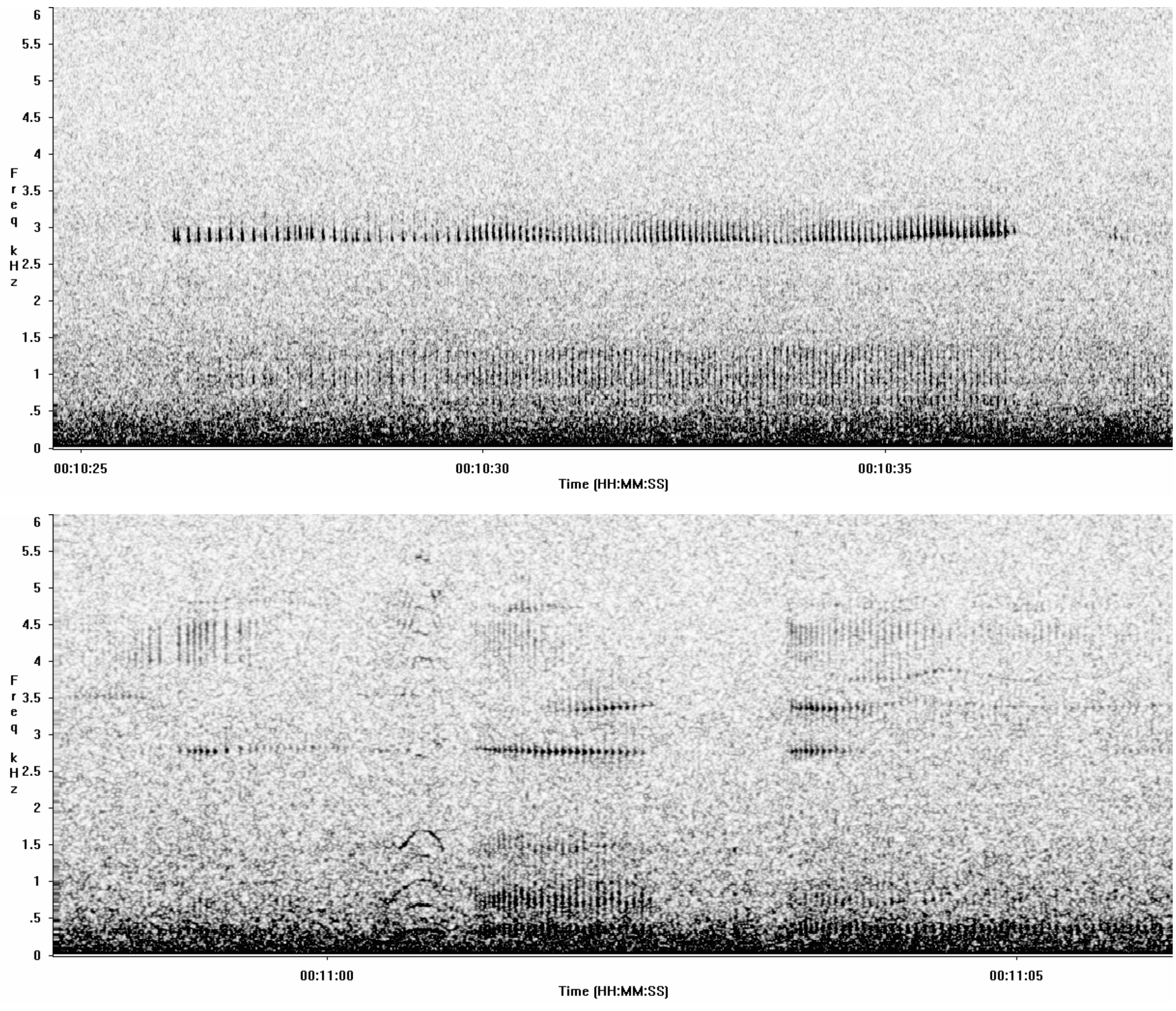

FIGURE 5.89. Possible narwhal clicks and a whistle at B10, 10 Aug 2007 16:48 (16384 point FFT, 1024 real points,).

Fin whale downsweeps were detected at stations CL20, CL35, CL50, CLN40 AND CLN80 between Sep 5th and Sep 13th 2007. Calls were first found opportunistically on CLN40 and CLN80, and more detections were obtained after checking adjacent recording stations for the same period. Thus, calls from this species are likely to be found more broadly, both temporally and geographically, once included in the classification algorithm. An example is provided in Figure 5.90.

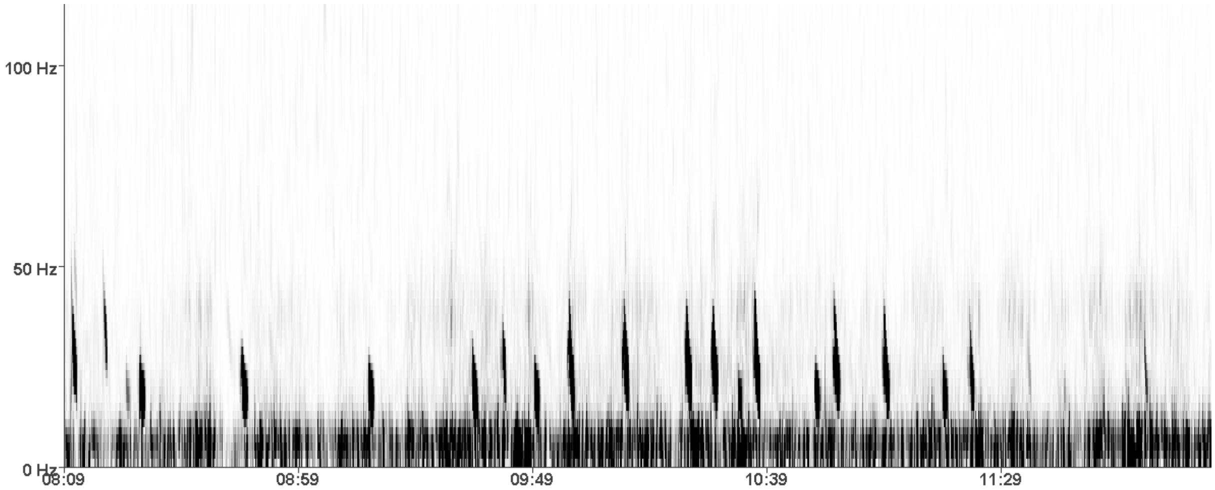

FIGURE 5.90. Fin whale calls at CLN80, 11 Sep 2007 01:07 (16384 point FFT, 1024 real points, 128 advance).

Killer Whales

While searching systematically for seal calls, examples of killer whale vocalizations were found in the data. John Ford, head of cetacean research at Department of Fisheries and Oceans in British Columbia, Canada, confirmed the identification and described the frequency structure and duration, as well as multiple element structure, as being very typical of killer whales. Killer whales were recorded at PLN40 on 18 Jul 2007, 22:42-23:49. There was a visual sighting of a killer whale on 21 Jul in the southern Chukchi near CL35. Figure 5.91 below shows examples of the vocalizations. A second recording of killer whales was discovered at PL20 on 3 Aug, 2007. Their sound spectrograms (Figure 5.92) look quite different from those recorded at PLN40; Dr. Ford confirmed these as originating from a different pod of whales.

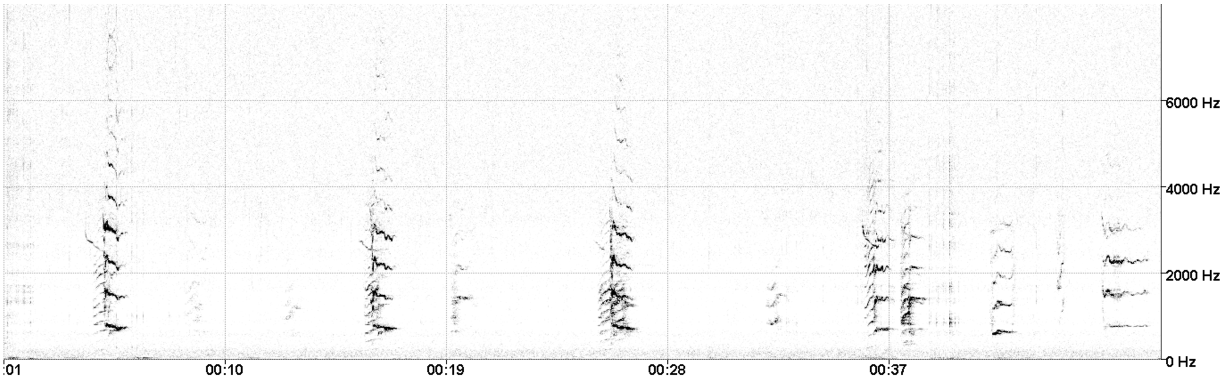

FIGURE 5.91: Killer whales, PLN 40, 18 Jul 2007 22:50 (16384 point FFT, 1024 real points, 128 advance).

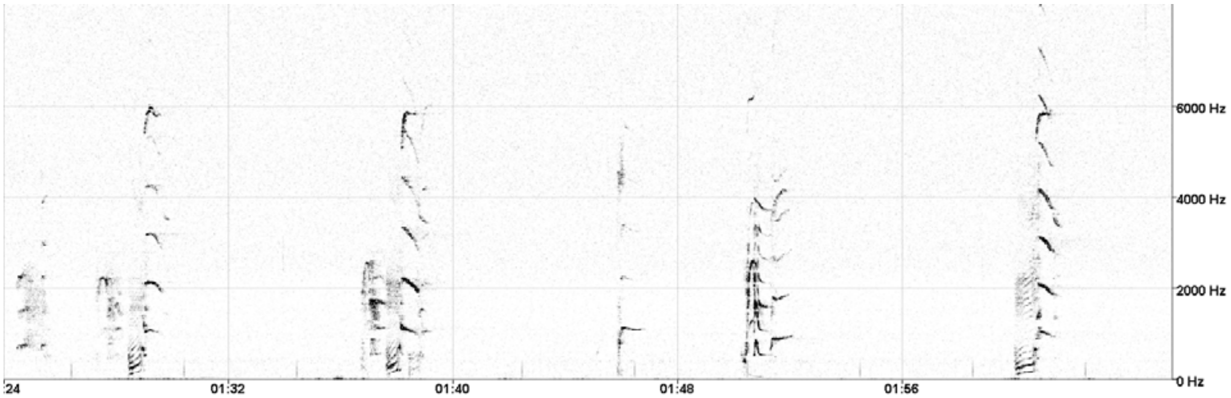

FIGURE 5.92: Killer whales, PL20, 3 Aug 2007 (16384 point FFT, 1024 real points, 128 advance).

Other signals of interest located in data set

A repetitive noise that occurred on the morning of 25 Sep triggered seismic detections on B35R. A spectrogram of about 1 minute of data from 0 to 200 Hz is shown in Figure 5.93. The basic character of the sound is a low frequency rumble, with a pair of impulses. The rumble could be due to currents, instrument self-noise or other environmental factors; however there is a regular double-thump which is not common in other noisy portions of the overall dataset. The source of this sound is unexplained.

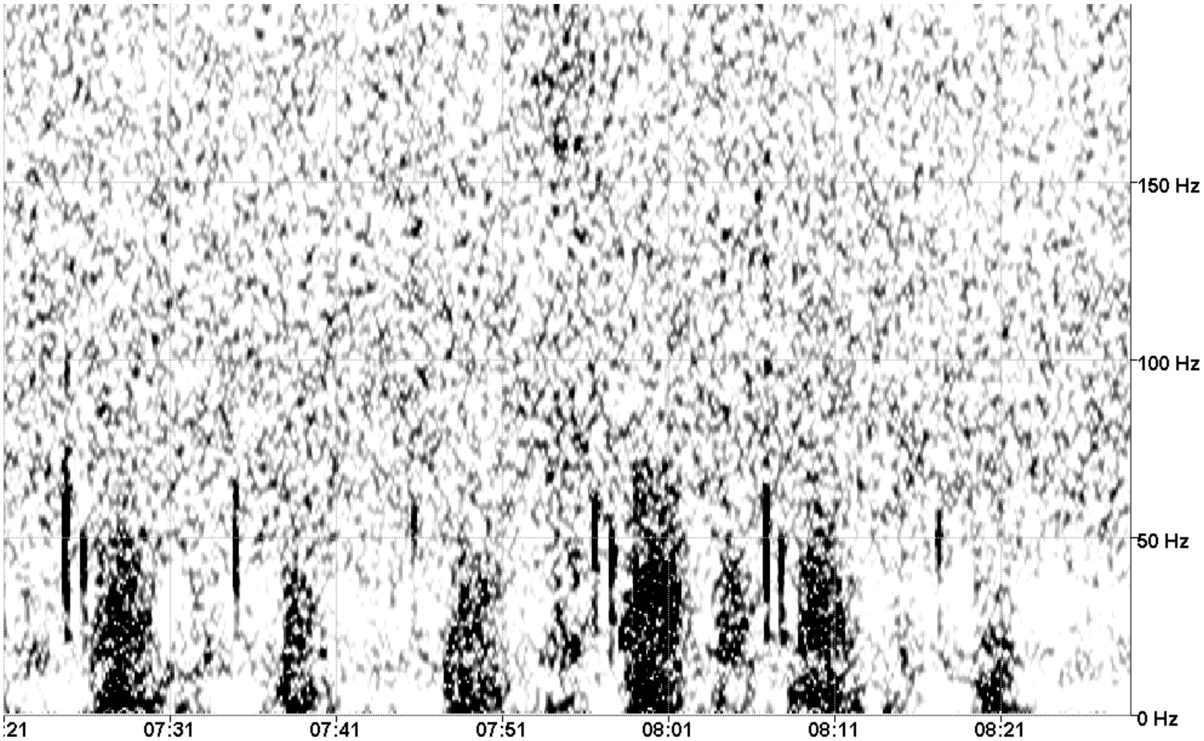

FIGURE 5.93. A zoomed spectrogram of the acoustic data from B35R showing approximately 1 minute of sound recording, 0 to 200 Hz (FFTSize 16384, real samples 1024, overlap 512, normalized).

CONCLUSIONS

The Chukchi Net Array provided information about ambient noise levels, shipping noise, seismic noise propagation and biological noise including marine mammal vocalizations in the Chukchi. Development activity is now ongoing to improve the effectiveness of the marine mammal vocalization classification procedures. Specifically, work is being directed at improving the bowhead classification methods to avoid false classifications of walrus grunts as bowhead calls. The results of analyses performed so far on the 2007 Chukchi data are summarized below:

1. The ambient noise during open water conditions appeared to be driven by weather-related processes. The mean level of the ambient noise followed the lower range of variation with frequency as defined by Wenz curves for given sea states, but low frequency shipping noise was is generally below the levels presented in the Wenz curves. This is due to the relatively low amount of shipping activity in the Chukchi. Large increases in measured noise levels at low frequencies correlated with periods of strong winds. The highest measured levels in active weather appear to be caused by water motion against the OBH hydrophones in the shallower water along the coast, rather than arising entirely from the increase in background noise. This suggests storm turbulence reaches the bottom quite strongly in water depths less than about 30 m.
2. Shipping noise levels at most OBH deployment locations often exceeded the 95th percentile ambient noise levels. These events were infrequent and caused mainly when vessels approached within a few kilometres of the recording stations.
3. Seismic survey noise levels decreased with distance from the survey in accordance with transmission loss rates measured during Sound Source Verification (SSV) measurements for those surveys. Noise from SOI's seismic surveys was detected at all times when those surveys were in progress. The array also detected other seismic survey noises during the period from 17 Aug to 8 Oct.
4. A short duration of seismic activity was detected on 8 Aug. These sounds appeared to originate from a location different than the Gilavar's position at that time and could not be explained.
5. Walruses were detected throughout the Chukchi Sea over much of Aug, more predominantly offshore except at Cape Lisburne where most detections were at the 5 mile (closest to shore) OBH location. There were clear detections of groups of walruses moving from far offshore to near shore, and then back out.
6. Bowheads were detected sporadically in the Chukchi Sea throughout Aug. The detections progressed from east to west, with Cape Lisburne providing the latest initial detections starting on Aug 24th. Some fall migrating bowheads were recorded moving past Wainwright in Sep and Oct but ambient sound masking reduced the ability to detect the majority of those calls by the automatic detector. On 7 and 17 Oct, ambient noise levels were very low and many bowhead calls were detected at Barrow. These calls were concentrated within 35 miles from the coast.
7. Belugas were detected only sporadically, at all recorders and throughout the monitoring season. These small numbers of detections do not provide strong evidence of systematic

use of the area by a large population of belugas, but they do confirm some animals are present.

8. Many other call types were detected through manual review of the OBH data. These included vocalizations from seals, narwhals, humpbacks, grey whales, orca and fin whales.

NOTES

Spectrogram Processing

This report contains many black-and-white spectrograms of interesting data from SOI's 2007 Chukchi Acoustic Monitoring Program. The horizontal axis of these figures is time and the vertical is frequency. The spectrograms that are labeled as "normalized" have been processed to maximize the visual contrast of the signal of interest for purposes of the discussion, and therefore the displayed traces do not provide a direct measure of the signals SPL. Each figure contains a description of how it was processed, including the following fields:

1. FFTSize: the number of points in each FFT. Since the 2007 Chukchi data has a sampling rate of 16384 Hz, a 4096 point FFT has 4 Hz resolution, and a 16384 point FFT has a 1 Hz resolution.
2. Real Samples: the number of actual data points in each FFT. Often this is less than the FFTSize. The actual data points are zero-padded out to the FFT size, which allows display of spectral content at a high frequency resolution, but also maintain a better time resolution. Since many of the signals of interest are short duration transients, we use fewer actual data points in the FFT window to avoid 'wash-out' in time of the signals of interest.
3. Overlap: The number of data points that are overlapped from one FFT to the next. Generally this is one half of the number of real samples, but it may be more to achieve greater time resolution of calls that change rapidly in frequency with time.
4. Window: The type of window applied to the data before FFT, so reduce spectral leakage. Generally we use the Reisz window which has minimal impact on the main lobe, and -22 dB side-lobes. There are many stronger windows which are appropriate for sinusoidal data; however we have found that this window is well suited to transient data analysis.
5. Normalized / Un-normalized: Most of the spectrograms shown in this report are normalized for display. Normalization optimizes the contrast in each region of the figure so that the reader can see both weak and intense signals at the same time. This process means the displayed gray levels or colours are no longer directly representative of sound spectral pressure level. The normalization scheme employed for the spectrograms is:
    a. For each frequency compute the average response for the entire file.
    b. For each time, compute a moving average of the results from step a), with a frequency width of 200 Hz.
    c. Normalize each time / frequency bin by the average of a), and the value of b) that is 300 Hz above the current frequency.

This presentation approach may or may not have been used in other studies. The method was developed specifically as a unified normalization technique to enhance both continuous tones from shipping which are suppressed by step a), and transients.

Acronyms and Abbreviations

The following acronyms and abbreviations are used in this document:

Ah	Ampere-Hours
ADC	Analog to Digital Converter
AEWC	Alaska Eskimo Whalers Commission
CPA	Closest Point of Approach
FFT	Fast Fourier Transform
GB	Giga Byte (1024 ^ 3)
GPS	Global Positioning System
Hz	Hertz
NMFS	National Marine Fisheries Service
NSB	North Slope Borough
OBH	Ocean Bottom Hydrophone
ROC	Receiver Operating Characteristic
ROV	Remote Operated Vehicle
SEL	Sound Exposure Level
SPL	Sound Pressure Level
SOI	Shell Offshore Incorporated
XML	Extendible Markup Language

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6. BEAUFORT SEA VESSEL–BASED MONITORING PROGRAM[1]

INTRODUCTION

This chapter presents the results of the marine mammal monitoring and mitigation program aboard vessels operating in the Beaufort Sea in 2006 and 2007 in support of seismic and shallow hazards data acquisition by Shell Offshore Inc. (SOI). Where appropriate, the 2006 and 2007 data were pooled to allow for multi–year analyses with increased power due to greater sample size.

Environmental conditions, ice cover in particular, varied greatly between 2006 and 2007. In order to allow the direct comparison of the area covered by ice between years, a standard area was defined in which to estimate ice cover in the Beaufort Sea (Fig. 6.1). Between early Jul and mid–Nov the average area covered by ice in the Beaufort Sea was 86,918 km^2 (33,559 mi^2) in 2006, compared to 46,496 km^2 (17,952 mi^2) in 2007 (Fig. 6.2). Different environmental conditions between years likely had different biological effects on marine mammal distribution and behavior that are not possible to quantify at this time.

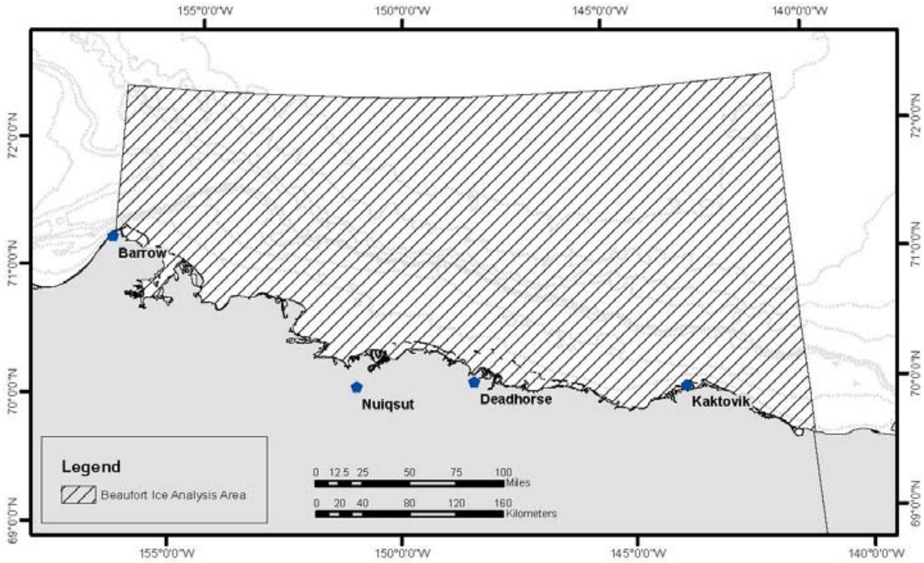

FIGURE 6.1. Shaded area denotes the area used to quantify ice cover in the Beaufort Sea in 2006 and 2007.

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[1] By Meaghan Jankowski, Mark Fitzgerald, Beth Haley, and Heather Patterson

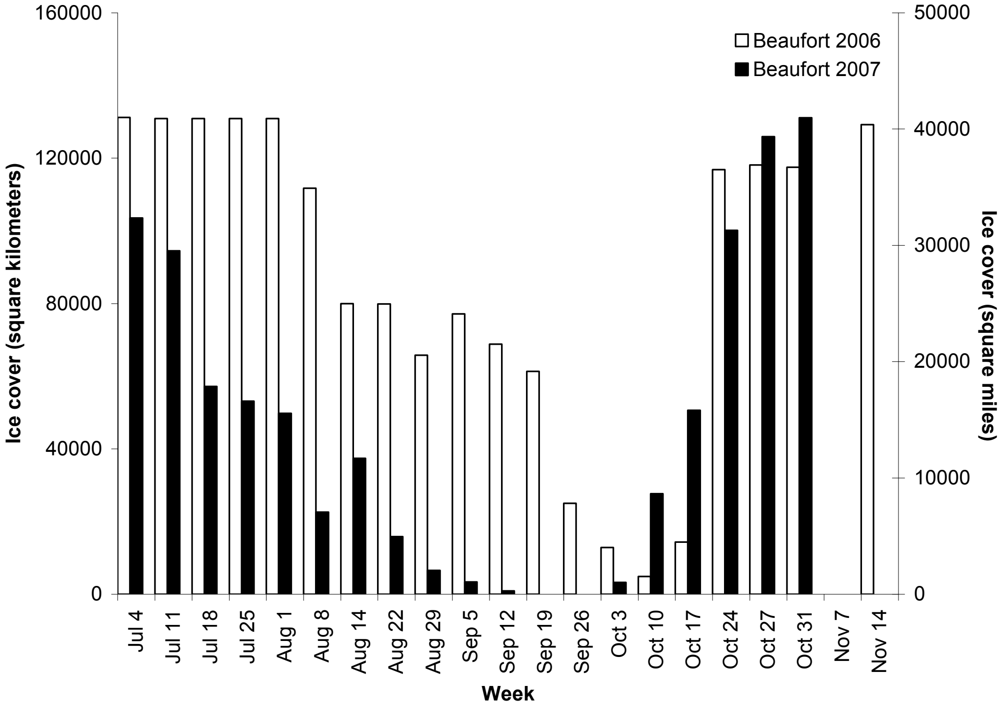

FIGURE 6.2. Weekly average number of square km and square miles of ice cover in the standardized area of the Beaufort Sea in 2006 and 2007.

The amount of effort expended in the Beaufort Sea also varied greatly between years, making direct comparisons of the data difficult. For non–seismic periods there was 57.3% less useable effort in 2007 compared to 2006, and <500 km of useable effort was collected during seismic periods in each year. Additionally, both shallow hazards surveys and seismic surveys were conducted in 2007, while only shallow hazards surveys were conducted in 2006.

Among the marine mammal species known to occur within the project area, five are cetaceans, four are pinnipeds, and one is an ursid (the polar bear). Two of the cetacean species, the bowhead and humpback whales, are listed as endangered under the U.S. Endangered Species Act (ESA). Humpback whales generally do not occur in the Beaufort Sea (Angliss and Outlaw 2007; NOAA Platforms of Opportunity database). For more details on the abundance, distribution, and conservation status of the marine mammal species likely to occur in the project area, please refer to Appendix F in the 2007 90–day report (Funk *et al.* 2008).

METHODS

Monitoring Tasks

The main purposes of the vessel–based monitoring program were to ensure that the provisions of the IHAs issued by NMFS and USFWS were satisfied, effects on marine mammals were minimized, and residual effects on animals were documented. Tasks specific to the monitoring program in the Beaufort Sea were the same as those described for the Chukchi Sea in Chapter 3.

Safety and Potential Disturbance Radii

Guidelines developed by NMFS and USFWS for establishment of safety and disturbance radii for marine mammals around airgun arrays in the Chukchi Sea are discussed in Chapter 3. The guidelines and associated requirements in the IHAs issued by NMFS and USFWS for the Chukchi Sea are generally the same for the Beaufort Sea and include monitoring of the 180 and 190 dB (rms) safety zones and the 160 dB (rms) disturbance zone. In 2006 and 2007 there was a requirement to implement special mitigation measures if specified numbers of bowhead cow/calf pairs (four) were observed within areas where received sound levels were ≥120 dB (rms) during fall migration in the Beaufort Sea. The IHA issued by NMFS required SOI to conduct aerial surveys and to notify the source vessel if four or more bowhead cow/calf pairs were seen within the 120 dB (rms) disturbance zone.

Beaufort Sea 2006–07.—Deep seismic surveys using large airgun arrays in the Alaskan Beaufort Sea were not performed in 2006 so comparing seismic airgun array sound source measurements for large airgun arrays between years was not possible. Results of the 2007 sound source measurements of the airgun arrays and mitigation guns on the *Gilavar* and *Henry Christoffersen* (*Henry C.*) are presented in Table 6.1. The measured safety and disturbance radii were larger than modeled predictions (Table 4.1 in Chapter 4 in Funk et al. 2008) and larger than the 2007 Chukchi Sea sound measurement results for the *Gilavar* airgun array. Sound levels produced by a four–airgun, 280–in^3 array towed by the *Henry C.* for shallow hazards surveys in 2006 were measured by Greeneridge Sciences Inc. (Table 6.1). In 2007 the *Henry C.* towed two 10–in^3 airguns; sound propagation from the two-airgun array and the single 10–in^3 mitigation gun was measured by JASCO in two locations. The larger of the distances at the two measurement locations for each sound level are presented in Table 6.1.

TABLE 6.1. Comparison of measurements of the 190, 180, 170, 160 and 120 dB rms distances (in km) for sound pulses from seismic and shallow hazards survey airgun arrays and mitigation guns deployed in the Beaufort Sea, Alaska, 2006 and 2007.

	Seismic Survey		Shallow Hazards Survey		
Received Level (dB rms)	*Gilavar* 24-Airguns 3147 in^3 2007	*Gilavar* Mitigation Airgun 30 in^3 2007	*Henry C.* 4-Airguns 280 in^3 2006	*Henry C.* 2-Airguns 20 in^3 2007	*Henry C.* Mitigation Airgun 10 in^3 2007
≥190	0.860	0.010	0.090	0.012	0.005
≥180	2.250	0.024	0.250	0.051	0.020
≥170	5.990	0.465	0.680	0.183	0.085
≥160	13.410	1.430	1.750	1.004	0.333
≥120	75.000	24.600	22.200	25.228	8.130

Visual Monitoring and Data Analysis Methods

For a detailed explanation of the visual monitoring and data analysis methods, please refer to the Methods section of Chapter 3 in this report. The following analyses are primarily based on data recorded during periods with useable effort as described in the *Methods* section of Chapter 3. Appendix Table C.5 includes all sighting regardless of usability criteria.

RESULTS

Monitoring Effort and Marine Mammal Encounter Results

Survey Effort

This section summarizes the visual monitoring effort from the various seismic survey and support vessels that operated within the Alaskan Beaufort Sea in 2006 and 2007. Overall, source vessels covered a combined trackline of 17,741 km (11,017 mi), while support vessels covered an additional 21,228 km (13,183 mi). The total MMO effort in the Beaufort Sea during 2006–07 was 20,903 km (12,981 mi, 2103 h), of which 9222 km (5727 mi, 754 h) or ~44% was useable, according to the usability criteria defined for cetaceans in the *Methods* section (Chapter 3). The amount of MMO watch effort from source and support vessels combined in 25 km^2 blocks in the Beaufort Sea project area is shown on Fig. 6.3. Note that actual amounts of useable effort were different for cetaceans, pinnipeds, and ursids due to different definitions of the "post–seismic" period and vessel proximity criteria for each species group (see *Useability Criteria* in *Methods* in Chapter 3). The main factors contributing to the large proportion of non–useable data were low visibility (<3.5 km or 2.2 mi), the proximity of another vessel, and high sea conditions (Bf > 5).

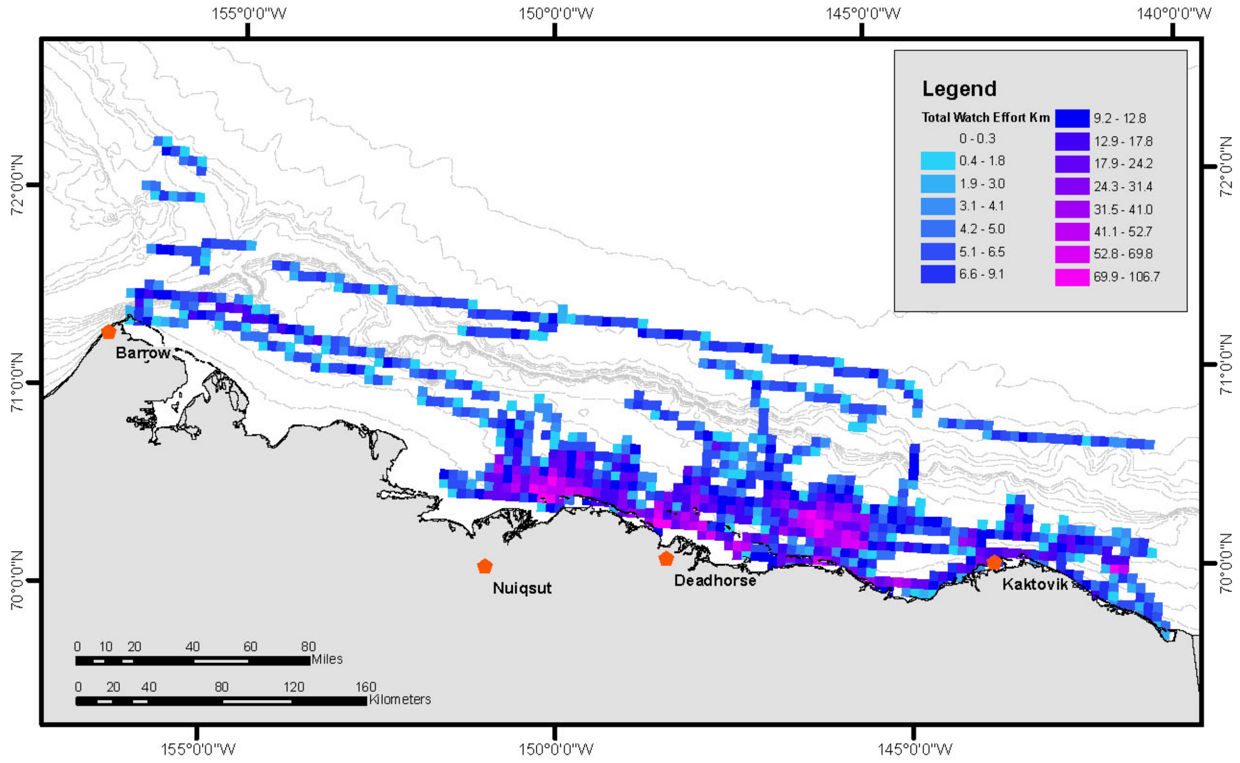

FIGURE 6.3. Total kilometers of useable MMO watch effort in 25 km^2 blocks during source and support vessel operations related to offshore seismic exploration activities in the Chukchi Sea in 2006 and 2007.

Average Beaufort wind force (Bf) in 2006 during daylight was Bf = 2 (range 0–7, *n* = 2664 records), and in 2007 during daylight was Bf = 3 (range 0 to 9, *n* = 7060 records). Useable observer effort by Beaufort wind force is shown for all vessels in 2006 and 2007 in Fig. 6.4. The distribution of useable observer effort was similar between the summer (Jul–Aug) and fall (Sep–Oct) in 2006, with most of the useable effort collected during conditions of Bf 1 and 2 (Fig. 6.4). This may have been due to the prevalence of ice in the Beaufort Sea in 2006, which tended to inhibit the formation of large waves. In summer of 2007, the distribution of useable effort was similar to 2006, with the majority of useable effort occurring at Bf 1 and 2. However, in the fall of 2007, wind conditions were generally stronger, and the majority of useable effort occurred in Bf 2–4 (Fig. 6.4). Appendix Tables C1–4 contain more detailed information on useable observation effort for cetaceans and pinnipeds/ursids from the source vessels and support vessels, in h, km, and mi, subdivided by seismic state and Beaufort wind force.

Source Vessels.—In 2006, the *Henry C.* was the only source vessel operating in the Alaskan Beaufort Sea, covering a trackline of 8213 km (5100 mi, 1464 h). MMOs were on watch for 5146 km (3196 mi, 527 h), of which 3418 km (2123 mi, 313 h) or 66% were considered useable for cetaceans. In 2007, seismic survey activities in the Alaskan Beaufort Sea were conducted by two source vessels, the *Henry C.* and the *Gilavar*, but the total amount of trackline of the two vessels (9528 km or 5917 mi) was similar to that of the single source vessel in 2006. In 2007 MMOs were on watch for 5092 km [3162 mi, 637 h], of which (1570 km [975 mi, 155 h] was considered useable for cetaceans. The lower proportion of effort that was useable in 2007 resulted from overall poorer weather conditions in that year.

The *Henry C.* conducted shallow hazard surveys in 2006 on a single day over 73 km (45 mi) of trackline, which resulted in only 59 km (37 mi) of useable seismic period effort (Fig. 6.5). This low amount of useable seismic period effort precluded comparisons between seismic and non–seismic periods using 2006 source vessel data. In 2007, MMO’s were on watch for 1664 km (1033 mi) of seismic effort, 135 km (84 mi) of which were considered useable (Fig. 6.5). The low amount of useable seismic effort in 2007 also precluded meaningful comparisons between seismic and non–seismic periods using source vessel data alone.

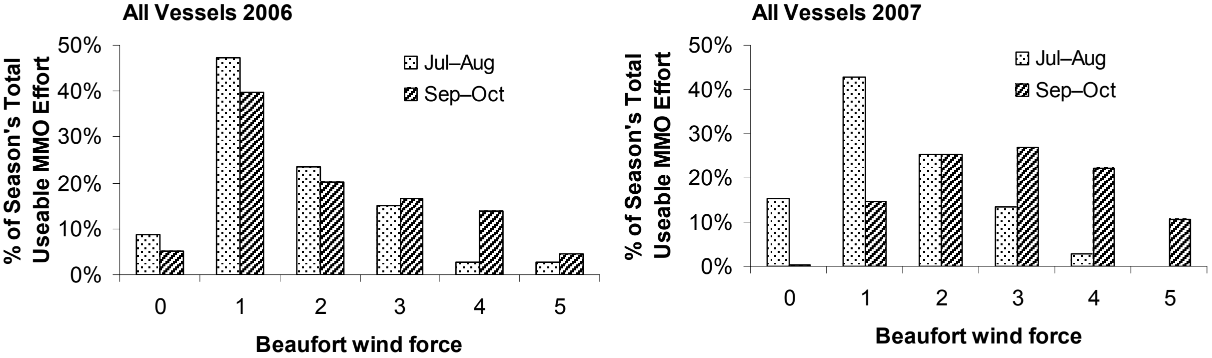

FIGURE 6.4. Percent of total useable marine mammal observer effort in summer (Jul–Aug) and fall (Sep–Oct) from all vessels in the Beaufort Sea study area, by Beaufort wind force in 2006 and 2007.

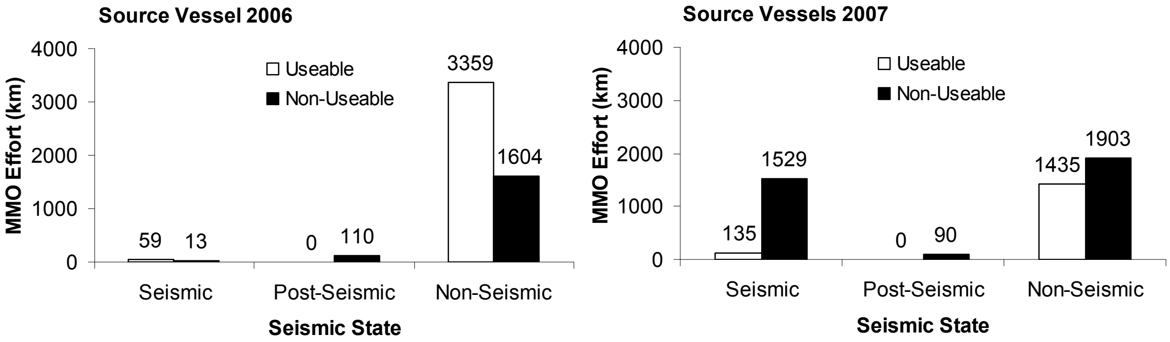

FIGURE 6.5. Marine mammal observer effort (km) from the source vessels in the Beaufort Sea study area by seismic state, comparing useable and non–useable effort, 2006 and 2007. Values presented in figures are rounded and may not match the total of un–rounded numbers presented in the text.

The majority of useable observer effort from source vessels in 2007 was collected in the fall (Sep–Oct), rather than the summer (Jul–Aug; Fig. 6.6). Therefore, the majority of useable source vessel data in 2007 was collected during the higher sea conditions that occurred in the fall as discussed above (Fig. 6.4). In 2006, the *Henry C.* had roughly the same amount of useable effort in the summer (Jul–Aug) and fall (Sep–Oct; Fig. 6.6), and sea conditions were relatively calm (mostly Bf 1 and 2, as discussed above; Fig. 6.4).

MMOs on board the *Henry C.* in 2006 collected 95% of useable data from the conning tower, at an eye–height of 14.5 m (15.8 yds), and the remaining useable data were collected from the bridge (eye–height 8.4 m or 9.2 yds). One observer was on watch aboard the *Henry C.* in 2006 for 3316 km (2059 mi, 305 h) of useable effort (91% of useable seismic effort and 97% of useable non–seismic effort) and two observers were on watch during the remaining 102 km (63 mi, 7 h) of useable effort.

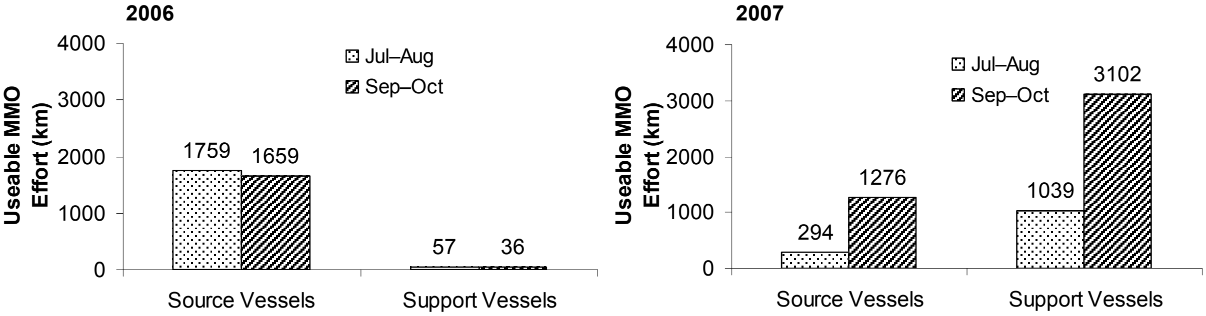

FIGURE 6.6. Useable marine mammal observer effort (km) from the source and support vessels in the Beaufort Sea study area by season (Jul–Aug versus Sep–Oct), 2006 and 2007. Values presented in figures are rounded and may not match the total of un–rounded numbers presented in the text.

Most of the useable 2007 source vessel data was also collected from the *Henry C.* so the majority of useable data in 2007 was collected from the conning tower (86% of the useable data). The remaining data were collected from the *Gilavar* bridge at an eye–height of 10.7 m (11.7 yds; 13% of the useable data), and the *Henry C.* bridge at an eye–height of 8.4 m (9.2 yds; 1%). One observer was on watch aboard the source vessels in 2007 for 991 km (615 mi, 94 h) of useable effort (67% of useable seismic effort and 63% of useable non–seismic effort), two observers were on watch during most of the remaining useable effort, and three MMOs were on watch for only 2% of useable non–seismic effort. There were no watches with three MMOs during seismic periods on the source vessels.

A portion of the data that was not useable was associated with MMO effort during periods of darkness which included a total of 827 km (514 mi) in 2007. Of this total, 69 km (43 mi) of seismic MMO effort occurred during nighttime power ups from one airgun. Also, in compliance with the 2007 IHA requirement that monitoring take place through the night if one or more power downs were implemented during daytime, a total of ~214 km (~133 mi) of MMO effort was carried out in darkness due to daytime power downs. The remaining 544 km (338 mi) of nighttime MMO effort from source vessels in 2007 occurred prior to and after power ups and near dawn and dusk. In 2006, there was a total of 142 km (88 mi) of MMO effort during periods of darkness, which was considered non–useable. No marine mammals were observed during periods of darkness in either 2006 or 2007 in the Beaufort Sea.

Support Vessels.—Industry support vessels that operated in the Alaskan Beaufort Sea in 2006 and contributed useable MMO effort included the *Gulf Provider*, the *Jim Kilabuk*, and the *Torsvik*. MMOs on board these support vessels were on watch in 2006 for 488 km (303 mi, 40 h), of which 93 km (58 mi, 9 h) or 19% were considered useable for cetaceans. In contrast, ~41% of MMO effort from support vessels was useable in 2007 (4142 km [2572 mi, 277 h] of 10,177 km [6320 mi, 899 h] total MMO effort). The useable 2007 support vessel effort was contributed by the vessels *American Islander*, *Gulf Provider*, *Jim Kilabuk*, *Kapitan Dranitsyn*, *Norseman II*, and *TOR Viking*.

Observation effort from support vessels was considered "seismic" if the vessel was within 15 km / 9 mi (for cetaceans) or 5 km / 3 mi (for pinnipeds and ursids) of a source vessel while the guns were firing (see *Methods* section in Chapter 3). No useable seismic period effort was collected from support vessels in the Beaufort Sea in 2006 (Fig. 6.7). MMO's in 2007 were on watch for 2087 km (1296 mi) of support vessel seismic effort, but only 291 km (181 mi) of that effort were considered useable (Fig. 6.7). However, more useable observer data were collected from support vessels compared to source vessels during non–seismic periods in 2007 (3850 km/2391 mi versus 1435 km/891 mi; Figs. 6.5 and 6.7).

Sea conditions were generally calm throughout 2006, and the small amount of useable effort was collected primarily in conditions of Bf 1 and 2 (Fig. 6.4). However, three–quarters of the support vessel data in 2007 was collected in the fall (Sep–Oct), when seas were generally rougher, and the majority of support vessel data was collected in Bf 2–4 (Fig. 6.4). All visual monitoring on the support vessels occurred from their respective bridges, which ranged in eye–height from 7.3–10.8 m (8.0 to 11.8 yds) in 2006, and 6.0–27.0 m (6.5–29.4 yds) in 2007. However, almost all (95%) of the useable data collected in 2007 were from the shorter support vessels (eye–height 6.0–10.8 m or 6.5–11.8 yds).

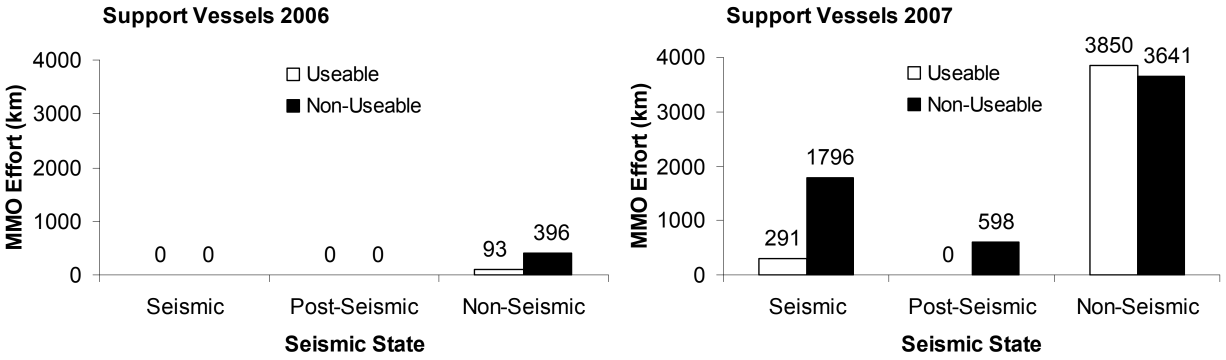

FIGURE 6.7. Marine mammal observer effort (km) from the support vessels in the Beaufort Sea study area by seismic state, comparing useable and non–useable effort, 2006 and 2007. Values presented in figures are rounded and may not match the total of un–rounded numbers presented in the text.

Only one observer was on watch at a time for the majority of useable support vessel effort collected in both 2006 and 2007 in the Beaufort Sea (~58% of 2006 useable effort and, in 2007 ~78% of total useable effort as well as ~78% of useable seismic effort). Two MMOs were on watch simultaneously for most of the remaining useable effort in 2006 and 2007 (~20% of useable seismic effort in 2007), and three MMOs were on watch for 9% of useable effort collected in 2006 and only 1% of total useable 2007 effort (but ~2% of useable 2007 seismic effort).

Some of the non–useable effort was associated with MMO effort during periods of darkness. In 2006, there were only 10 km (6 mi, 1 h) of MMO effort before dawn and after dusk. A total of 1038 km (645 mi, 151 h) of support vessel MMO effort occurred during periods of darkness in 2007. No marine mammals were observed during periods of darkness in 2006 or 2007 in the Beaufort Sea from support vessels.

Visual Sightings of All Marine Mammals

Total Sightings.—In the Beaufort Sea in 2006, an estimated 340 individual marine mammals were seen in 315 groups by MMOs from all vessels combined (Table 6.2). The numbers of marine mammal sightings regardless of usability criteria for source and support vessels during 2006 and 2007 are listed in Appendix Table C.5. Eight marine mammal species were identified, including bowhead whale, gray whale, minke whale, bearded seal, ringed seal, spotted seal, Pacific walrus, and polar bear. There was little useable effort from support vessels in 2006, and most sightings were recorded from the source vessel (*Henry C.*; Table 6.2; Fig. 6.7). However, the few cetacean sightings from 2006 were recorded only from the support vessels operating near point Barrow (Table 6.2).

More marine mammal sightings were recorded in 2007 than 2006, with an estimated 485 individual marine mammals seen in 363 groups by MMOs from all vessels combined during periods with useable effort (Table 6.2). In 2007, about half as many cetacean and seal sightings were recorded from source vessels compared to support vessels. No Pacific walrus sightings were recorded in 2006, but five sightings (nine individuals) were recorded from support vessels in 2007. More polar bear sightings were recorded from source than support vessels in 2007 (Table 6.2). The decrease in useable source vessel sightings from 2006 to 2007 and the higher number of support vessel sightings in 2007 were likely related in part to changes in the amount of useable effort between years and vessel types (see Figs. 6.5 and 6.7).

TABLE 6.2. Numbers of useable sightings (number of individuals) of marine mammals observed during MMO watches in the Beaufort Sea (2006 and 2007) from the source and support vessels.

	Source Vessel(s)		**Support Vessels**		***Total All Vessels***	
Species	**2006**	**2007**	**2006**	**2007**	***2006***	***2007***
Cetaceans						
Unidentified Whale	0	1 (1)	1 (1)	1 (1)	***1 (1)***	***2 (2)***
Mysticetes						
Bowhead Whale	0	5 (15)	0	15 (36)	***0***	***20 (51)***
Gray Whale	0	0	2 (3)	1 (1)	***2 (3)***	***1 (1)***
Minke Whale	0	0	0	1 (1)	***0***	***1 (1)***
Unidentified Mysticete Whale	0	2 (2)	0	6 (13)	***0***	***8 (15)***
Total Cetaceans	***0***	***8 (18)***	***3 (4)***	***24 (52)***	**3 (4)**	**32 (70)**
Seals						
Bearded Seal	11 (11)	15 (15)	1 (1)	24 (40)	***12 (12)***	***39 (55)***
Ringed and Spotted Seals[a]	293 (316)	90 (96)	4 (4)	187 (239)	***297 (320)***	***277 (335)***
Unidentified Pinniped[b]	0	0	0	2 (2)	***0***	***2 (2)***
Total Seals	***304 (327)***	***105 (111)***	***5 (5)***	***213 (281)***	**309 (332)**	**318 (392)**
Pacific Walruses	***0***	***0***	***0***	***5 (9)***	**0**	**5 (9)**
Polar Bears	***3 (4)***	***7 (11)***	***0***	***1 (3)***	**3 (4)**	**8 (14)**
Total All Marine Mammals	***307 (331)***	***120 (140)***	***8 (9)***	***243 (345)***	**315 (340)**	**363 (485)**

[a] Includes all ringed, spotted, and unidentified seal sightings.

[b] Unidentified pinniped sightings throughout the rest of this chapter will be allocated to bearded seals, based on the ratio of Pacific walrus sightings to bearded seal sightings in the Beaufort Sea.

For the combined 2006–07 useable sightings data, seals were the most commonly sighted marine mammals, followed by cetaceans, polar bears, and Pacific walruses (Table 6.2). The ringed/spotted seal category in 2006 was comprised of 18% ringed seals, 18% spotted seals, and 63% unidentified seals. In 2007 the breakdown was 30% ringed seals, 26% spotted seals, and 44% unidentified seals. A summary of all sightings within the Beaufort Sea, including sightings made during periods of non–useable MMO effort is presented in Appendix Table C.5.

***Total Sightings by Season.*—**In 2006, there were over twice as many marine mammal sightings in the fall compared to the summer (224 versus 91; Fig. 6.8). There was little effort from support vessels in 2006 and most of the sightings were from the source vessel (*Henry C.*). Useable effort was reduced in fall compared to summer and these data suggest that more animals may have been present in the Beaufort Sea study area in Sep–Oct than Jul–Aug 2006.

A similar increase in fall sightings was apparent in 2007 from source vessels, which could also be explained by the larger amount of useable effort in the fall (Fig. 6.6). Effort from support vessels was much greater in 2007 compared to 2006 and more marine mammal sightings were recorded from sources vessels than support vessels in both summer and fall 2007. The numbers of sightings were similar from support vessels during summer and fall 2007, however the number of sightings from source vessels was over three times higher in the fall than summer. The overall numbers of sightings from both vessel types combined were higher in the fall that summer for both 2006 and 2007.

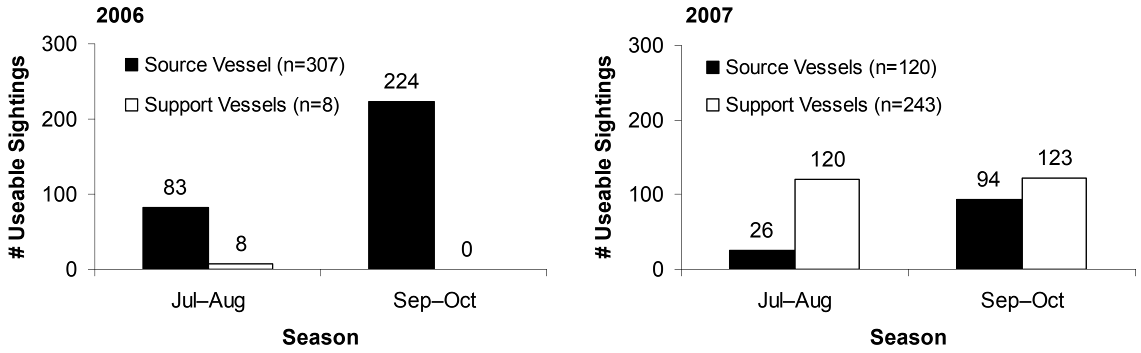

FIGURE 6.8. Number of useable marine mammal sightings in the Beaufort Sea from the source and support vessels during the summer (Jul–Aug) and fall (Sep–Oct), 2006 and 2007.

Detection Rates by Season.—The marine mammal detection rate from the source vessel was more than two times higher in the fall (Sep–Oct) than the summer (Jul–Aug; Fig. 6.9) in 2006, a year with greater ice coverage in the Beaufort Sea than 2007. Useable effort from support vessels was low in 2006, and support vessel detection rates should be viewed with caution.

Useable effort from support vessels in 2007 was sufficient for meaningful analyses of sightings data, and the marine mammal detection rate was over three times higher from support vessels in the summer compared to the fall (Fig. 6.9). The trend of higher detection rates in the summer was also present in the 2007 source vessel data, but the summer detection rate should be viewed with caution due to the low amount of effort (Fig. 6.9). The detection rate from source vessels was over two times greater than from the support vessels in the fall 2007, which was the only category with sufficient data to make meaningful comparisons of the two vessel groups (Fig. 6.9). The detection rate from source vessels was also twice as high in the fall of 2006 compared to the fall of 2007 (Fig. 6.9).

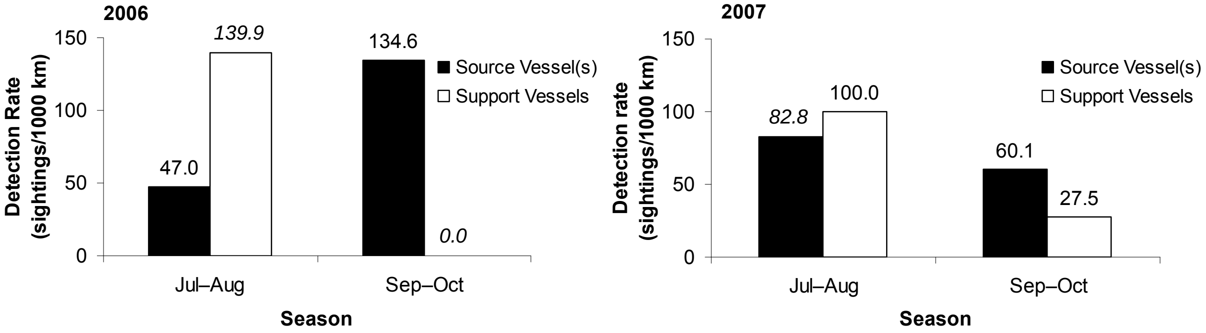

FIGURE 6.9. Detection rate of useable marine mammal sightings in the Beaufort Sea from source and support vessels during the summer (Jul–Aug) and fall (Sep–Oct), 2006 and 2007. Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

Total Sightings by Seismic State.—All 315 useable 2006 marine mammal sightings occurred during non–seismic periods (Fig. 6.10) due to the limited extent of seismic activities in 2006 (72 km of seismic shooting on one day resulted in only 59 km of useable seismic period effort from the source vessel; Fig. 6.5). Of the 363 useable marine mammal sightings recorded in 2007 in the Beaufort Sea, 21 sightings were made during seismic periods, and 342 were made during non–seismic periods (Fig. 6.10). The small number of useable seismic period sightings was likely related to the small amount of useable seismic period effort in 2007 (135 km/84 mi for source vessels and 291 km/181 mi for support vessels; Figs. 6.5 and 6.7). For a breakdown of useable seismic versus non–seismic sightings for each species group, see Appendix Tables C.6–C.9.

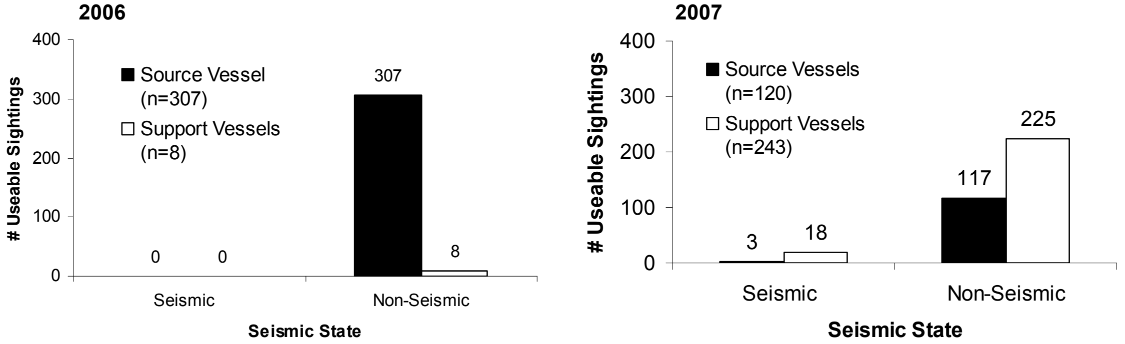

FIGURE 6.10. Number of useable marine mammal sightings in the Beaufort Sea from the source and support vessels during seismic and non–seismic periods, 2006 and 2007.

Detection Rates by Seismic State.—The 2006 non–seismic marine mammal detection rates were similar between source and support vessels, though the support vessel detection rate was based on very little useable effort (Fig. 6.11). There was very little useable seismic period effort in 2006, so a meaningful comparison of detection rates for seismic and non–seismic periods was not possible.

In 2007, the marine mammal detection rate was lower from source vessels than support vessels during seismic periods, but higher during non–seismic periods (Fig. 6.11). Detection rates from the source vessels may have been lower during seismic periods due to avoidance of seismic survey activity by marine mammals..

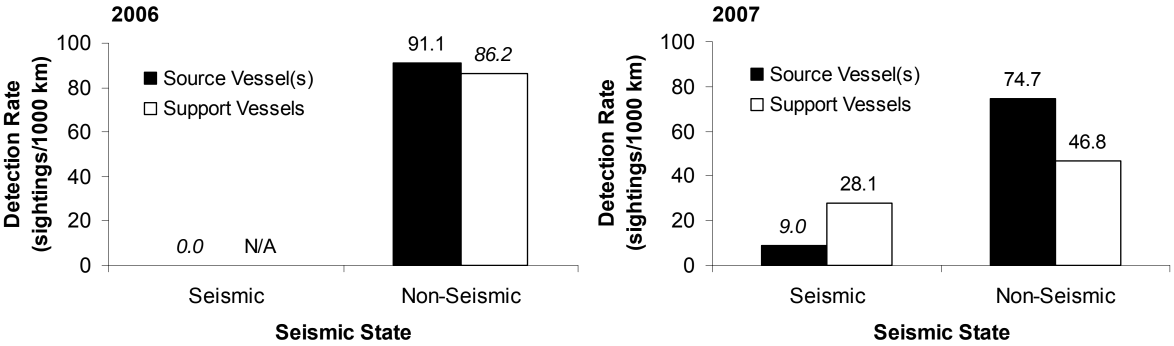

FIGURE 6.11. Detection rate of useable marine mammal sightings in the Beaufort Sea from source and support vessels during seismic and non–seismic periods, 2006 and 2007. Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution. Note: N/A means Not Applicable.

Cetaceans

Sightings

Total Sightings.—Cetacean sightings were not reported from the source vessel in 2006; the few cetacean sightings in 2006 were recorded from the support vessels (three sightings of four whales; Table 6.3). This was in contrast to 2007 when there were 70 whales sighted in 32 groups, including eight sightings from the source vessels (Table 6.3). The difference in the numbers of cetacean sightings between years may have resulted from differences in ice cover which was more prevalent in 2006. The number of cetacean sightings from support vessels was higher than from source vessels in both 2006 and 2007 (Table 6.3), suggesting possible cetacean avoidance of source vessels. The total numbers of marine mammal sightings regardless of usability criteria for source and support vessels during 2006 and 2007 are listed in Appendix Table C.5.

Overall, bowhead whale was the most commonly identified cetacean in the Beaufort Sea in 2006–07 (*n* = 51 individuals in 20 groups). Of the 51 bowhead whales reported, two were recorded as juveniles. The next most common cetacean species was gray whale, followed by minke whale (Table 6.3). Given the relative numbers of bowhead, gray, and minke whales recorded during the surveys, most of the eight unidentified mysticete whale sightings and the three unidentified whale sightings (Table 6.3) were likely to have been of bowhead whales.

TABLE 6.3. Numbers of useable cetacean sightings (number of individuals) recorded during MMO watches in the Beaufort Sea (2006 and 2007) from the source and support vessels.

	Source Vessel(s)		**Support Vessels**		***Total All Vessels***	
Species	**2006**	**2007**	**2006**	**2007**	***2006***	***2007***
Cetaceans						
Unidentified Whale	0	1 (1)	1 (1)	1 (1)	***1 (1)***	***2 (2)***
Mysticetes						
Bowhead Whale	0	5 (15)	0	15 (36)	***0***	***20 (51)***
Gray Whale	0	0	2 (3)	1 (1)	***2 (3)***	***1 (1)***
Minke Whale	0	0	0	1 (1)	***0***	***1 (1)***
Unidentified Mysticete Whale	0	2 (2)	0	6 (13)	***0***	***8 (15)***
Total Cetaceans	***0***	***8 (18)***	***3 (4)***	***24 (52)***	**3 (4)**	**32 (70)**

Detection Rates by Season.—In 2006, no cetaceans were recorded by MMOs from the source vessel, and the low amount of effort from support vessels precluded meaningful analyses of seasonal cetacean detection rates (Table 6.4). The only cetaceans observed in the Beaufort Sea during vessel–based operations in 2006 were recorded from support vessels during the summer season (Jul–Aug).

More cetacean sightings were recorded in 2007 (32 sightings) than 2006 (3 sightings; Table 6. 4). Cetacean detection rates from support vessels in 2007 were twice as high in the summer (Jul–Aug) compared to the fall (Sep–Oct; Table 6.4). A similar comparison cannot be made for source vessel data in 2007 due to the low amount of useable effort in the summer (Table 6.4). During fall 2007, cetacean detection rates were higher from source vessels compared to support vessels (Table 6.4), possibly due to the generally higher observation height of the source vessels.

TABLE 6.4. Detection rates (# groups per 1000 km) for useable cetacean sightings during summer and fall from ***(A)*** source vessels, and ***(B)*** support vessels in the Beaufort Sea (2006 and 2007). Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

	2006			2007		
Season	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**
A. Source Vessel(s)						
Jul–Aug	0	1759.5	0.0	0	294.2	*0.0*
Sep–Oct	0	1658.7	0.0	8	1275.8	6.3
B. Support Vessels						
Jul–Aug	3	57.2	*52.5*	9	1039.1	8.7
Sep–Oct	0	35.6	*0.0*	15	3102.4	4.8

Detection Rates by Seismic State.—The small amount of useable effort during seismic periods in 2006 and 2007 in the Beaufort Sea (Table 6.5) precluded meaningful comparisons of detection rates between seismic and non–seismic periods. Sufficient effort was available during non–seismic periods in 2007 when cetacean detection rates were similar between source and support vessels (Table 6.5). Cetacean detection rates from the source vessels were higher during non–seismic than seismic periods in 2007 (Table 6.5), but the effort during seismic periods was low and these results should be viewed with caution. Differences in ice conditions between the two years may also have contributed to the higher cetacean detection rate in 2007. For a break–down of useable cetacean species sightings by seismic state, see Appendix Table C.6.

TABLE 6.5. Detection rates (# groups per 1000 km) for useable cetacean sightings during the different seismic states from useable MMO effort by ***(A)*** the source vessels, and ***(B)*** the support vessels in the Beaufort Sea (2006 and 2007). Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

	2006			2007		
Seismic State	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**
A. Source Vessel(s)						
Seismic	0	59.3	*0.0*	0	134.5	*0.0*
Non-Seismic	0	3358.9	0.0	8	1435.5	5.6
B. Support Vessels						
Seismic	0	0.0	N/A	3	291.2	*10.3*
Non-Seismic	3	92.8	*32.3*	21	3850.3	5.5

Note: N/A means Not Applicable.

In addition to comparing cetacean detection rates between seismic and non-seismic periods based on useable data from source and support vessels, seismic and non-seismic detection rates were also compared among various vessel types based on useable vs. all data (i.e., useable and non-useable data combined; Table 6.6). This was done to determine what effect the use of non-useable data may have on calculations of cetacean detection rates. For this analysis cetacean detection rates were calculated from the source vessels (*Gilavar* and *Henry C.*), from all support vessels combined, from the *Gilavar* alone, and from support vessels during the periods when they operated as chase vessels for the *Gilavar*. Chase vessel activities were concentrated within a few km of the *Gilavar* allowing for a comparison of the two vessel types operating in the same area. Non-chase support vessels operated over a much wider area and were often not in the same area of the Beaufort Sea as the *Gilavar*. Much of the activity of the *Henry C.* was independent of the *Gilavar* and did not require the use of chase vessels.

For all comparisons with sufficient effort to draw conclusions (>500 km), cetacean detection rates based on all data combined were lower than rates based on useable data. This would be the expected result since overall sighting conditions based on useable data were better than conditions that included non-useable data. When considering all data combined, cetacean detection rates were higher during seismic than non-seismic periods suggesting that cetaceans may not have avoided the seismic survey activities in the Beaufort Sea in 2007. Comparisons of cetacean detection rates during seismic and non-seismic periods based on useable data were mixed, however the data were insufficient to draw firm conclusions.

TABLE 6.6. Cetacean detection rates (sightings/1000km of trackline) from all source vessels, all support vessels, the *Gilavar*, and *Gilavar* chase vessels during seismic and non-seismic periods in the Beaufort Sea 2007 based on useable data and all data (useable and nonuseable) combined. Bold figures indicate values base on <500 km of effort.

	Cetacean Detection Rate			
	Useable Data		All Data	
	Seismic	Non-seismic	Seismic	Non-seismic
All Source Vessels	**0.0**	5.6	8.4	3.0
All Support Vessels	**10.3**	5.5	5.7	4.7
Gilavar	**0.0**	**0.0**	9.0	**0.0**
Gilavar Chase Vessels	**8.5**	8.4	5.5	4.7

Distribution

Initial Sightings Relative to Vessels.—The bearing and distance to cetaceans when first detected were determined for all useable sightings (Figs. 6.12 and 6.13). The reference point for the distance to animals from the source vessels was the airgun array. For the support vessels the observer station was used as the reference point. There were no useable cetacean sightings during seismic periods in either 2006 or 2007 and there were no useable cetacean sightings from the source vessels in 2006, therefore comparisons of the distribution of sightings between seismic and non–seismic periods were not possible.

Cetaceans sighted from the source vessels during 2007 were located ahead or abeam of the vessel (Fig. 6.12). All useable sightings were from the *Henry C.* and all but one was located outside the 180 dB (rms) safety radius (51m or 56 yd), although no sightings occurred during seismic activity. Most cetaceans sighted from the support vessels during both 2006 and 2007 were also initially sighted ahead or abeam of the vessel, (Fig. 6.13). This resulted from observers focusing most of their search effort forward and to the sides of the vessels, however a few sightings were recorded aft of support vessels.

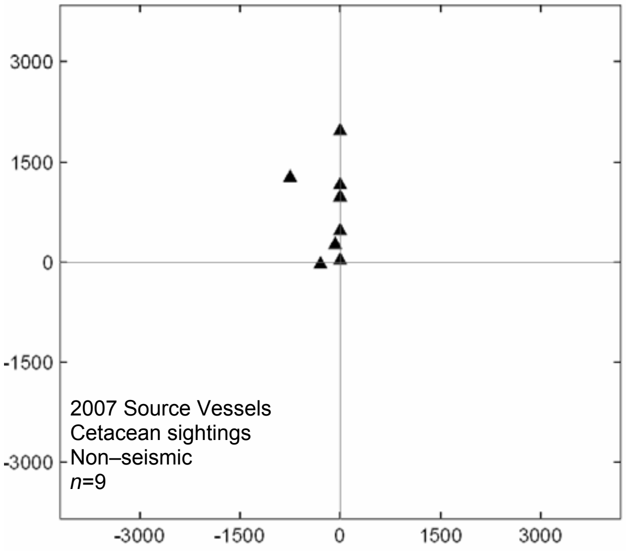

FIGURE 6.12. Relative location of useable non–seismic cetacean sightings from the source vessel in the Beaufort Sea, 2007. The 180 dB (rms) safety radius (51m or 56 yd) is not shown. The sighting locations indicate distance (m) from the airgun array located 300 m (328 yd) aft of the observer station. The distance between x and y axis tick marks (1500 m) = 0.9 mi.

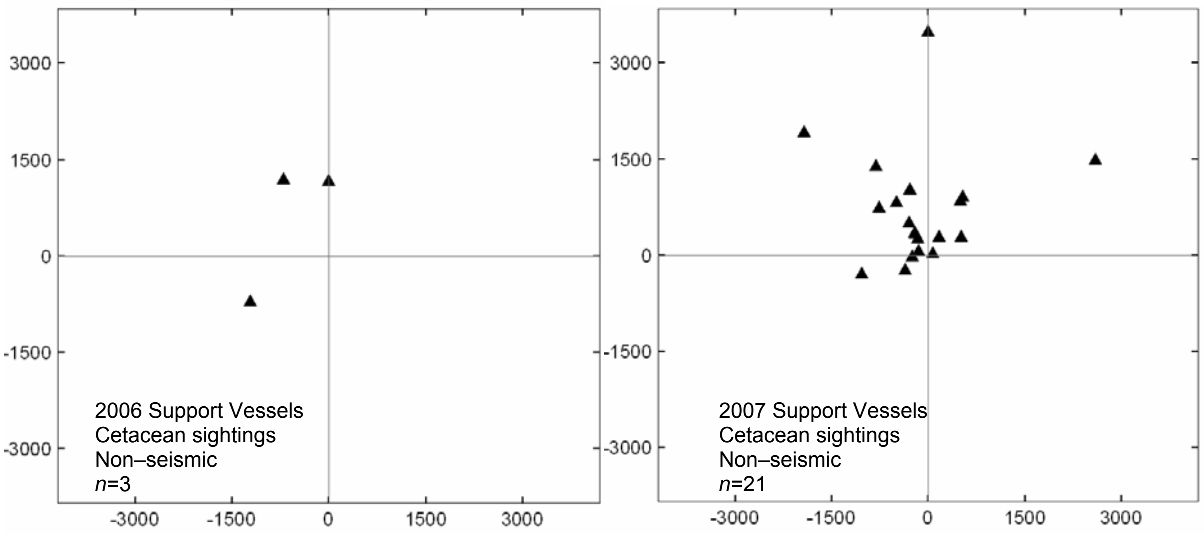

FIGURE 6.13. Relative locations of useable cetacean sightings from the support vessels during 2006 and 2007 during non–seismic periods in the Beaufort Sea. The locations indicate distance (m) from the observer station. The distance between x and y axis tick marks (1500 m) = 0.9 mi.

Closest Point of Approach.— There was little difference in cetacean CPAs from source and support vessels in 2006 and 2007. Most cetacean CPA data were recorded during non–seismic periods. However, the data were insufficient to make meaningful comparisons of CPAs and the analysis should be viewed with caution (Table 6.7).

TABLE 6.7. Closest observed points of approach (CPA) of cetaceans to the airguns of the source vessels or to the observers on the support vessels during seismic and non–seismic periods during the 2006 and 2007 Beaufort Sea surveys.

Effort Category	**Mean CPA[a] (m)**	**s.d.**	**Range (m)**	***n***
2006				
Source Vessels Seismic	-	-	-	-
Source Vessels Non-Seismic	-	-	-	-
Source Vessels Mean	-	-	-	-
Support Vessels Seismic	-	-	-	-
Support Vessels Non-Seismic	981	720	150-397	3
Support Vessels Mean	***981***	***720***	***150-397***	***3***
2007				
Source Vessels Seismic	-	-	-	-
Source Vessels Non-Seismic	887	677	114-2064	8
Source Vessels Mean	***887***	***677***	***114-2064***	***8***
Support Vessels Seismic	860	679	350-1631	3
Support Vessels Non-Seismic	981	950	80-3500	21
Support Vessels Mean	***973***	***878***	***80-3500***	***24***

[a] CPA = *Closest Point of Approach*. For source vessels this value is the marine mammal's closest point of approach to the airgun array, for support vessels this value is the marine mammal's closest point of approach to the MMO/vessel.

- means no data

Cetacean Detection Rates as a Function of Distance from Ice.—Cetacean detection rates were calculated for all cetacean sightings in the Beaufort Sea from all vessels combined in 2006 and 2007 (Tables 6.8 and 6.9). The amount of effort within most distance–from–ice categories and the small number of cetacean sightings were insufficient to make meaningful comparisons of cetacean detection rates as a function of distance from ice in 2006 or 2007 (Tables 6.8 and 6.9). Most cetacean sightings were recorded further than 20 km from ice.

TABLE 6.8. Number of useable cetacean sightings, useable effort, and detection rates (sightings per 1000 km) by distance from ice from all vessels operating in the Beaufort Sea, 2006.

Ice Bin	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (Sightings/1000 km)**
Cetaceans			
≥10% Ice Cover	0	1102	0
<10% Ice Cover	0	57	0
0-5 km from Ice	0	591	0
5-10 km from Ice	0	437	0
10-15 km from Ice	2	189	10.6
15-20 km from Ice	0	116	0
>20 km from Ice	1	1019	1.0

TABLE 6.9. Number of useable cetacean sightings, useable effort, and detection rates (sightings per 1000 km) by distance from ice from all vessels operating in the Beaufort Sea, 2007.

Ice Bin	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Cetaceans			
≥10% Ice Cover	0	319	**0**
<10% Ice Cover	0	153	0
0-5 km from Ice	1	211	4.7
5-10 km from Ice	0	95	0
10-15 km from Ice	0	94	0
15-20 km from Ice	0	126	0
>20 km from Ice	31	4713	6.6

Cetacean Detection Rates as a Function of Water Depth.—In 2006, more cetacean sightings were recorded in water 50–200 m (55 – 219 yd) deep than in other depth categories (Table 6.10). Although the cetacean detection rate was greatest in the mid–water–depth category, the amount of survey effort was insufficient to support strong conclusions. In 2007, cetacean detection rates were similar in the <50 m and 50–200 m water–depth categories with greater survey effort in both depth categories than in 2006 (Table 6.11). No cetacean sightings were recorded at depths >200 m (219 yd) but survey effort in this depth category was low.

TABLE 6.10. Number of useable cetacean sightings, useable effort, and detection rates (# sightings per 1000 km) from all vessels as a function of water depth in the Beaufort Sea, 2006.

Depth Ranges	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Cetaceans			
<50 m	0	3458.3	0.0
50-200 m	3	52.7	56.9
>200 m	0	0.0	0.0

TABLE 6.11. Number of useable cetacean sightings, useable effort, and detection rates (# sightings per 1000 km) from all vessels as a function of water depth in the Beaufort Sea, 2007.

Depth Ranges	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Cetaceans			
<50 m	29	4950.4	5.9
50-200 m	3	485.4	6.2
>200 m	0	275.7	0.0

Behavior

Movement.—Movement was recorded for six cetacean sightings from source vessels during 2007, all during non–seismic periods. Of these, five animals appeared to be moving in a direction that was neutral to the vessel's heading and one animal was swimming away from the vessel. There were no cetacean sightings with movement data recorded from source vessels during the 2006 season.

During the 2007 season, a total of 14 cetacean sightings from support vessels had movement data recorded. All sightings occurred during non–seismic periods. Ten of the cetaceans sighted from support vessels were moving in a neutral direction, two were swimming towards the vessel, and two were swimming away from the vessel. These data do not suggest any particular pattern of cetacean movement relative to vessels during non–seismic periods.

In 2006, movement was recorded for three cetacean sightings from support vessels. All were during non–seismic periods and all animals were swimming in a direction that was neutral to the vessel's heading.

Initial Behavior.—Initial behavior was recorded for eight cetacean sightings from the source vessels in 2007. Surface active was recorded as the first observed behavior for seven cetaceans, and the remaining animal was observed swimming/traveling. All of these sightings were made during non–seismic periods.

Initial behavior was recorded for 24 cetacean sightings from the support vessels in 2007 (Fig. 6.14). Three sightings occurred during seismic periods; two animals were observed swimming/traveling and the behavior of the third animal was recorded as "other". For behaviors during non–seismic periods, surface active was the behavior recorded most frequently, followed by swim, other, and look. The number of initial behaviors recorded during seismic periods was insufficient to make meaningful comparisons of behaviors between seismic and non–seismic periods.

During the 2006 season there were three sightings of cetaceans from support vessels for which behavior was recorded. All animals were swimming/traveling.

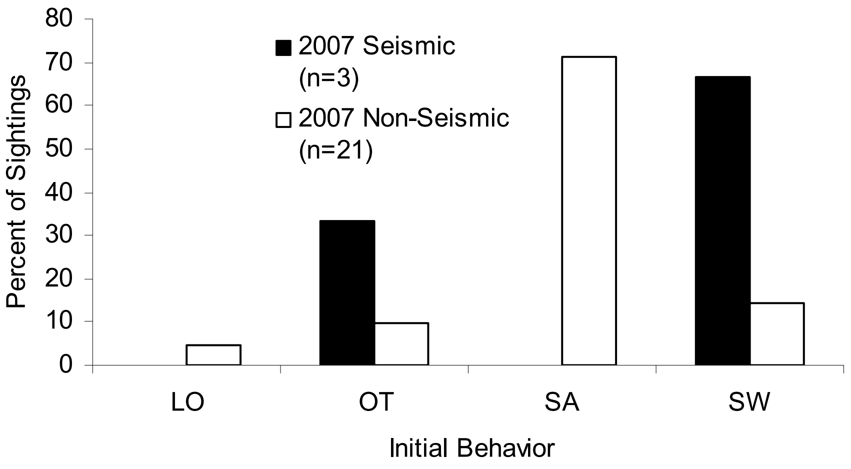

FIGURE 6.14. Initial behavior of cetaceans sighted from support vessels during seismic and non–seismic periods in the Beaufort Sea 2007. LO = Look, OT = Other, SA = Surface Active, SW = Swim.

***Reaction Behavior.*—**Reaction behavior was recorded for only one of the eight cetacean sightings from source vessels in 2007. This was of an animal that changed direction during the course of the sighting. No cetaceans were observed from the source vessels in 2006. Reaction behavior codes can be found in the *Methods* section of Chapter 3.

Reaction behavior was recorded for 7 cetaceans from support vessels in 2007. Three of the sightings were during seismic periods; none of these animals displayed an observable reaction to the seismic survey activity. Of the remaining four sightings, which occurred during non–seismic periods, there were two sightings during which animals splashed, one sighting during which the animal changed direction, and one during which the animal looked at the vessel (spyhopped). There were no sightings of cetaceans from support vessels for which reaction data were recorded during the 2006 season.

Cetacean Detection Rates Relative to Received Sound Levels

Cetacean detection rates from support vessels as a function of received sound levels resulting from seismic survey activity in the Beaufort Sea in 2007 are presented in Table 6.12. Cetacean detection rates were higher in the areas where received sound levels were 130–149 and 160–169 dB re 1 µPa rms compared to other 10–dB sound level categories and to locations where received levels were <120 dB rms. However, the numbers of km of useable effort were low in many of the 10–dB bins, and detection rate comparisons should be viewed with caution. There was no useable support vessel cetacean effort in bins ≥120 dB in 2006.

TABLE 6.12. Detection rates of cetaceans from the support vessels, divided into 10–dB (re 1 µPa rms) sound–level bins during the Beaufort Sea survey 2007. Detection rates in italics are based on < 500 km (311 mi) of useable effort and should be viewed with caution.

Received Sound Level (dB re1 µPa rms)	Number of Detections	Effort (km)	Detections / 1000 km
<120	2	825.9	2.4
120-129	0	176.3	*0.0*
130-139	1	88.1	*11.4*
140-149	1	151.7	*6.6*
150-159	0	161.3	*0.0*
160-169	2	116.6	*17.2*
170-179	0	13.2	*0.0*

Estimated Number of Marine Mammals Potentially Ensonified

***Estimates from Direct Observations.*—** The number of seals directly observed within areas where received sound levels were ≥160 and 180 dB rms provided a minimum estimate of the number of individuals potentially exposed to sounds at these levels. For this analysis the data were not filtered using the usability criteria outlined in the *Methods* section in Chapter 3. Table 6.13 presents the number of seals exposed to received levels ≥160, 170, and 190 dB rms based on direct observations. It is possible that some seals present within these areas were not detected by observers and the estimates likely underestimate the number of individuals ensonified.

In 2007 there were 14 cetacean sightings, involving 25 individual animals from the *Gilavar* while the airguns were operating. Of these, six sightings occurred while the mitigation gun was firing and eight sightings occurred while the full array was in operation. For the six sightings occurring during times when the mitigation gun was firing, the animals were well outside the 180 dB radius of the mitigation gun so it is unlikely that these cetaceans were exposed to sounds ≥180 dB rms. Of the eight sightings occurring during full array operation, the animals were well outside the 180 dB radius on four occasions and were not likely exposed to sounds ≥180 db rms. The four remaining sightings resulted in power downs (Table 6.14). For three of the four sightings that resulted in power downs, the animals dove below the surface within the 180 dB radius before the airgun array was powered down and it is likely that these animals were briefly exposed to sounds ≥180 dB rms. The animals involved in the fourth sighting also dove before the airgun array was powered down, however the animals were ahead of the vessel at a distance of nearly 2 km (1.25 mi; sighting 383, Table 6.14). Measured sound levels were considerably greater to the side and stern of the vessel than off the bow of the vessel, it is possible that the actual sound levels received at the location of the animals were <180 dB rms. However the animals were near the edge of the 180 dB (rms) radius and could have been exposed to received levels ≥180 dB (rms).

There were no cetacean observations while airguns were in operation during shallow hazards surveys from the *Henry C.* in 2007 or 2006. The estimate of the number of cetaceans exposed to ≥180 dB rms based from direct observation is zero.

TABLE 6.13. Total number of cetaceans observed within the ≥160 and 180 dB re 1 µPa (rms) radii of seismic airguns in the Beaufort Sea in 2006 and 2007.

Received Sound Exposure Level (dB re 1 µPa rms)	Individuals 2006	Individuals 2007
≥160	0	18(31)
≥180	0	4(7)

TABLE 6.14. List of power downs for cetaceans sighted within the *Gilavar's* 180 dB safety radius (2250 m) during the Beaufort Sea seismic survey (12 Sep-8 Oct 2007). The full airgun array (3147 in^3) was firing at initial sightings. All animals were likely exposed to sound levels ≥180 dB with the possible exception of whales included in Sighting ID 383 as discussed in the text. Reactions to the vessel included none (NO) and splash (SP).

Sighting ID	Species	Group Size	Date	Water Depth (m)	Distance (m) to Airguns at First Detection	CPA (m) to Operating Airguns Before Mitigation	Reaction to Vessel
382	Unidentified whale	1	19-Sep	29.8	1400	1400	NO
383	Bowhead whale	2	19-Sep	28.1	1919	1919	SP
386	Bowhead whale	1	19-Sep	26.1	1400	1400	NO
391	Unidentified whale	3	26-Sep	33.5	1124	1124	NO

Estimates Extrapolated from Density.—Estimates of cetacean densities based on useable effort for 2007 are shown in Table 6.15. Densities of bowhead whales were greater than densities of other cetaceans, and bowhead density was higher in summer than fall. The amount of useable effort and the low number of cetacean sightings were not sufficient to calculate estimates of cetacean densities in 2006.

TABLE 6.15. Estimated densities of cetaceans in the Alaskan Beaufort Sea during the summer (Jun–Aug) and fall (Sep–Nov) 2007 seasons based on useable effort. Densities are corrected for *f*(0) and *g*(0) biases.

		No. individuals / 1000km^2	
		Summer	Fall
Vessel Type	**Species**	**Non-Seismic**	**Non-Seismic**
Source Vessels			
	Bowhead Whale	-	2.8
	Unidentified Mysticete Whale	-	0.4
	Unidentified Whale	-	0.2
	Source Vessel Total	**-**	**3.3**
Support Vessels			
	Bowhead Whale	7.4	3.5
	Gray Whale	0.5	0.0
	Minke Whale	0.0	0.7
	Unidentified Mysticete Whale	0.7	1.3
	Unidentified Whale	0.0	0.1
	Support Vessel Total	**8.6**	**5.5**
All Vessels			
	Bowhead Whale	5.3	3.3
	Gray Whale	0.4	0.0
	Minke Whale	0.0	0.5
	Unidentified Mysticete Whale	0.5	1.0
	Unidentified Whale	0.0	0.1
	All Vessel Total	**6.1**	**4.9**

The estimated numbers of cetaceans that might have been exposed to various levels of received sounds during the 2007 season are summarized in Table 6.16. These values are from SOI's 2007 operations 90–d report (Funk et al. 2008). The amount of useable effort from vessels directly involved with seismic operations in the Beaufort Sea in 2007 was not sufficient to produce reliable density estimates. As an alternative, all daylight effort and sightings from these vessels were used to calculate the density estimates used in estimating exposures (for details see Funk et al. 2008). Note that the estimated numbers in Table 6.16 represent the cetaceans that would have been exposed had the animals not shown localized avoidance of the airguns or the ship itself. Many of the animals calculated to be within the 180 or 190 dB (rms) zones would likely have moved away before being exposed to sounds that strong.

During the 2007 shallow hazard operations it was not possible to reliably estimate densities of animals during seismic periods as very little seismic activity occurred. Based on non–seismic densities calculated using all daylight effort, it was estimated that one cetacean could have been exposed 1.5 times to sound levels ≥160 dB (rms) and no cetaceans were exposed to levels ≥180 dB (rms).

TABLE 6.16. Estimated numbers of individual cetaceans exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual within the Beaufort Sea during the 2007 season. Requested number of takes is also shown.

	A. Based on Non-seismic density		**B. Based on Seismic density**		
Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures per Individual**	**Individuals**	**Exposures per Individual**	**Requested Take**
≥160	16	19	20	19	2729
≥170	9	11	11	11	
≥180	5	6	6	6	
≥190	3	4	4	3	

Seals

Sightings

Total Sightings.—There were 332 individual seals sighted in 309 different groups by MMOs in the Beaufort Sea in 2006 (Table 6.17). Almost all of these sightings were recorded from the source vessel, which contributed almost all of the useable effort in 2006 (Figs. 6.5 and 6.7). The numbers of seals sighted in 2007 (*n* = 392 in 318 groups) were similar to the numbers in 2006, but twice as many seal sightings were recorded from support compared to source vessels (Table 6.17). This probably reflected the relative amounts of useable effort contributed by the source and support vessels in 2007. Overall, the most commonly identified seals in 2006 and 2007 were ringed/spotted seals, followed by bearded seal (Table 6.17). Most unidentified seals that are included in the ringed/spotted seal category were likely ringed seals given the known distribution of this species in the study area. The total numbers of marine mammal sightings regardless of usability criteria for source and support vessels during 2006 and 2007 are listed in Appendix Table C.5.

Although ice coverage in the Beaufort Sea was greater in 2006 than 2007, the only sightings of seals hauled out on ice occurred in 2007 and were recorded from the support vessels (Table 6.17). Source vessels generally do not operate near ice, making sightings of animals hauled out on ice unusual. The useable effort and sightings in 2006 were almost all recorded from the *Henry C*. In 2007, support vessels contributed a higher proportion of useable effort and often scouted the position of ice floes, increasing the probability of detecting seals on ice. Due to the low number of sightings of seals on ice, these data were pooled with in–water seal sightings in later analyses. Interestingly, the number of hauled out ringed/spotted seal and bearded seal sightings were similar (Table 6.17), even though the smaller seals are known to outnumber bearded seals in the study area.

TABLE 6.17. Numbers of useable seal sightings (number of individuals) in water and on ice from the source and support vessels in the Beaufort Sea (2006 and 2007).

	Source Vessel(s)		**Support Vessels**		***Total All Vessels***	
Species	**2006**	**2007**	**2006**	**2007**	***2006***	***2007***
Seals in Water						
Bearded Seal[a]	11 (11)	15 (15)	1 (1)	18 (28)	***12 (12)***	***33 (43)***
Ringed and Spotted Seals[b]	293 (316)	90 (96)	4 (4)	180 (229)	***297 (320)***	***270 (325)***
Seals on Ice or Land						
Bearded Seal	0	0	0	8 (14)	***0***	***8 (14)***
Ringed and Spotted Seals[b]	0	0	0	7 (10)	***0***	***7 (10)***
Total Seals	***304 (327)***	***105 (111)***	***5 (5)***	***213 (281)***	**309 (332)**	**318 (392)**

[a] Two single "unidentified pinniped" sightings from the support vessels in 2007 were included as bearded seals, based on the ratio of Pacific walrus sightings to bearded seal sightings in the Beaufort Sea.

[b] Includes all ringed, spotted, and unidentified seal sightings.

Detection Rates by Season.—In 2006, seal detection rates from the source vessel were almost three times higher in the fall than summer (Table 6.18). The sighting rate from support vessels in 2006 was greater in the summer than fall (when no sightings were recorded), however low amounts of effort make interpretation of these detection rate data problematic.

In 2007, seal detection rates from source vessels were similar during the summer and fall, but the effort was relatively low during the summer period. Seal detection rates from support vessels in 2007 were ~four times greater during summer than fall. Some of this difference may have been related to differences in ice conditions between years and seasons.

TABLE 6.18. Detection rates (# groups per 1000 km) for useable seal sightings during summer and fall from ***(A)*** source vessels, and ***(B)*** support vessels in the Beaufort Sea (2006 and 2007). Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

	2006			**2007**		
Season	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**
A. Source Vessel(s)						
Jul–Aug	81	1765.4	45.9	20	314.0	*63.7*
Sep–Oct	223	1664.2	134.0	85	1597.9	53.2
B. Support Vessels						
Jul–Aug	5	57.2	*87.4*	111	1214.6	91.4
Sep–Oct[a]	0	35.6	*0.0*	102	4561.6	22.4

[a] Inlcudes two sightings of unidentified pinnipeds.

Detection Rates by Seismic State.—Seal detection rates were higher from source and support vessels during non–seismic compared to seismic periods in 2007 suggesting localized avoidance of seismic activities. The difference in detection rates between seismic and non–seismic periods was much greater from source vessels than support vessels, although effort from source vessels during seismic periods was low and the analysis should be viewed with caution. During non–seismic periods in 2007, seal detection rates were higher from the source vessels compared to the support vessels (Table 6.19), possibly because of the generally higher observation height on the source vessels. Seal detection rates from source vessels during non–seismic periods were higher in 2006 than 2007 (Table 6.19). Effort during seismic periods in 2006 was insufficient to make any meaningful comparisons of seal detection rates during seismic and non–seismic periods. For a break–down of useable seal species sightings by seismic state, see Appendix Table C.7.

TABLE 6.19. Detection rates (# groups per 1000 km) for useable seal sightings during seismic and non–seismic periods from ***(A)*** source vessels, and ***(B)*** support vessels in the Beaufort Sea (2006 and 2007). Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

	2006			**2007**		
Seismic State	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**
A. Source Vessel(s)						
Seismic	0	59.3	*0.0*	3	334.3	*9.0*
Non-Seismic	304	3370.3	90.2	102	1576.3	64.7
B. Support Vessels						
Seismic	0	0.0	N/A	14	843.2	16.6
Non-Seismic[a]	5	92.8	*53.9*	199	4933.0	40.3

[a] Inlcudes two sightings of unidentified pinnipeds.

Note: N/A means Not Applicable.

In addition to comparing seal detection rates between seismic and non-seismic periods based on useable data from source and support vessels, seismic and non-seismic detection rates were also compared among various vessel types based on useable data vs. all data (i.e., useable and non-useable data combined; Table 6.20). This was done to determine what effect the use of non-useable data may have on calculations of seal detection rates. For this analysis cetacean detection rates were calculated from the source vessels (*Gilavar* and *Henry C.*), from all support vessels combined, from the *Gilavar* alone, and from support vessels during the periods when they operated as chase vessels for the *Gilavar*. Chase vessel activities were concentrated within a few km of the *Gilavar* allowing for a comparison of the two vessel types operating in the same area. Non-chase support vessels operated over a much wider area and were often not in the same area of the Beaufort Sea as the *Gilavar*. Much of the activity of the *Henry C.* was independent of the *Gilavar* and did not require the use of chase vessels.

For all comparisons seal detection rates based on all data combined were lower than rates based on only on useable data. This would be the expected result since overall sighting conditions based on useable data were better than conditions that included non-useable data. Seal detection rates were much higher during non-seismic than seismic periods when comparing data from all source vessels and all support vessels suggesting possible localized seal avoidance of seismic survey activities in the Beaufort Sea in 2007. This was not the case when comparing seal detection rates from the *Gilavar* and its chase vessels where seal detection rates were generally greater during seismic than non-seismic periods (Table

6.20). However for most of the comparisons of seismic and non-seismic detection rates from the *Gilavar* and its chase vessels there were insufficient data to draw meaningful conclusions.

TABLE 6.20. Seal detection rates (sightings/1000km of trackline) from all source vessels, all support vessels, the *Gilavar*, and *Gilavar* chase vessels during seismic and non-seismic periods in the Beaufort Sea 2007 based on useable data and all data (useable and nonuseable) combined. Bold figures indicate values based on <500 km of effort.

	Seal Detection Rate			
	Useable Data		All Data	
	Seismic	Non-seismic	Seismic	Non-seismic
All Source Vessels	**9.0**	64.7	4.2	59.9
All Support Vessels	16.6	40.3	12.6	33.7
Gilavar	**7.0**	**5.7**	**3.2**	3.4
Gilavar Chase Vessels	**16.6**	9.8	12.6	7.2

Distribution

Initial Sightings Relative to Vessels.—The bearing and distance to seal sightings from the source vessels are shown in Figs. 6.15 and 6.16. In 2007 there were only three useable seal sightings during seismic periods. These data were insufficient to make a meaningful comparison between sighting distributions during seismic and non–seismic periods. All but one of the sightings during 2007 was within the vessel's 190 dB radius. This sighting occurred during a non–seismic period. As with cetaceans, most seals were sighted in front or to the side of the vessel, though during non–seismic periods there were numerous sightings of seals aft of the vessel as well.

Bearing and distance to seal sightings from the support vessels are shown in Figs. 6.17 and 6.18. As there were only five useable sightings during seismic periods in 2007 and none in 2006, the data were insufficient to make a meaningful comparison of sighting distributions during seismic and non–seismic periods. Nearly all seals sighted from the support vessels were at or ahead of the vessel position and all but one, a seal sighted during non–seismic periods in 2007, were sighted within ~500m (0.6mi) of the vessel. This sighting would undoubtedly have been made during unusually calm weather.

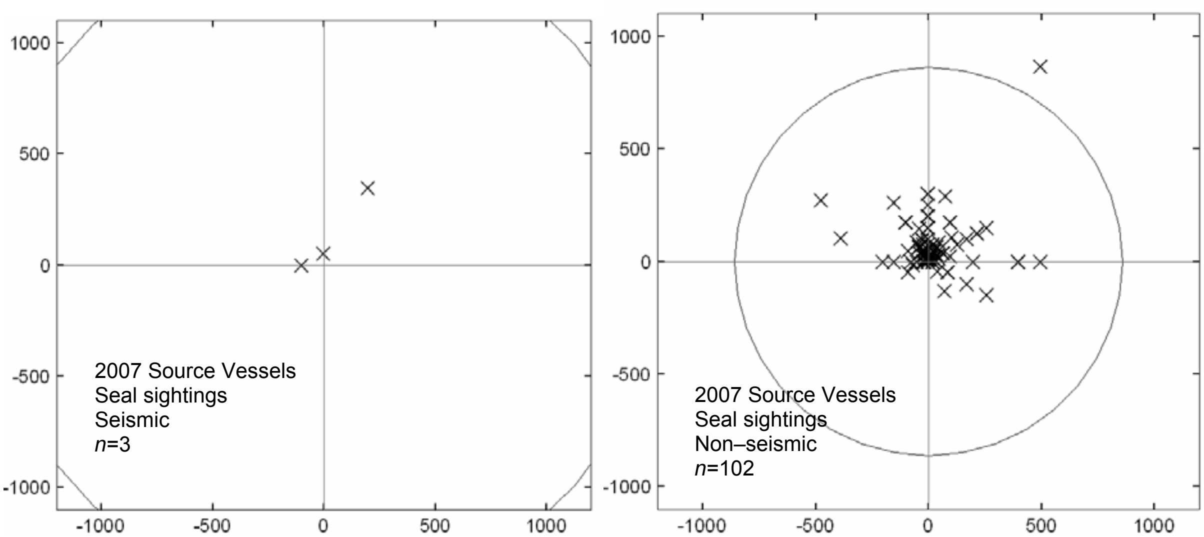

FIGURE 6.15. Relative location of useable seismic and non–seismic seal sightings from the source vessel in the Beaufort Sea, 2007. The vessel's 190dB radius (860m or 940.5 yd) is shown. The sighting locations indicate distance (m) from the airgun array located 300 m (328 yd) aft of the observer station. The distance between x and y axis tick marks (500 m) = 0.3 mi.

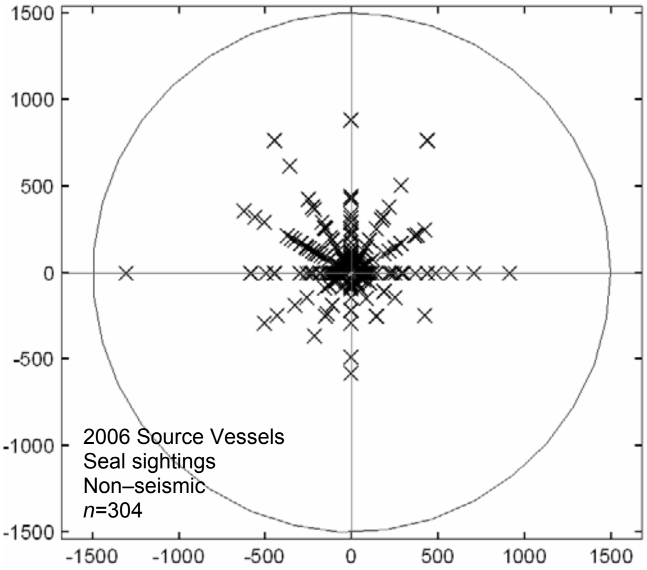

FIGURE 6.16. Relative location of useable non–seismic seal sightings from the source vessel in the Beaufort Sea, 2006. The vessel's 190dB radius (12m or 13.1 yd) is not shown. The sighting locations indicate distance (m) from the airgun array located 300 m (328 yd) aft of the observer station. The distance between x and y axis tick marks (500 m) = 0.3 mi.

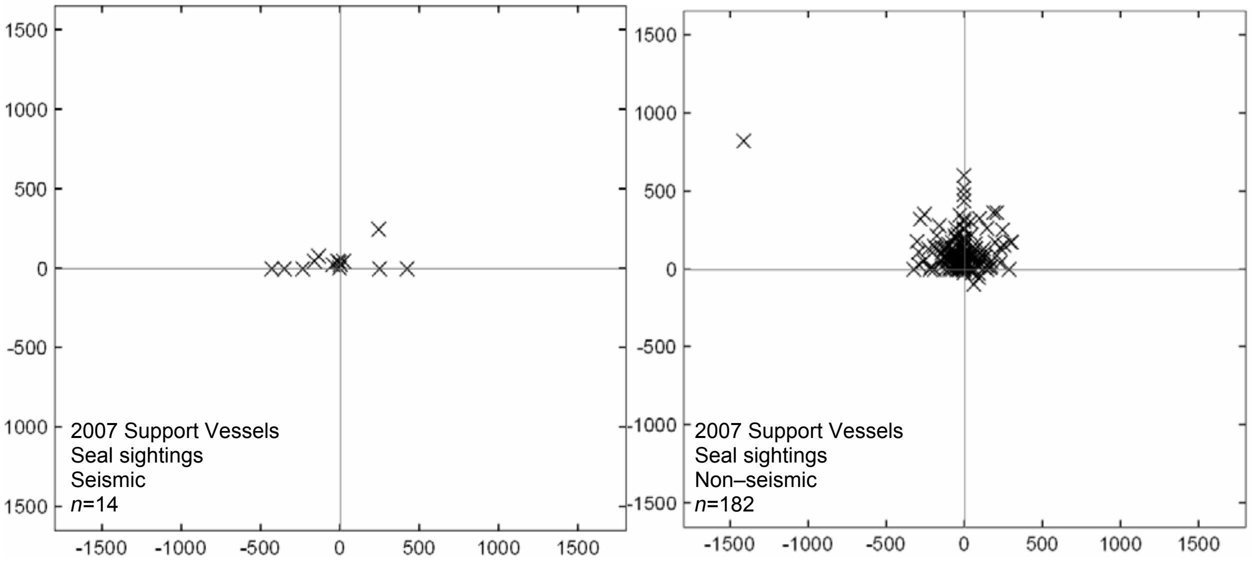

FIGURE 6.17. Relative location of useable seismic and non–seismic seal sightings from the support vessels in the Beaufort Sea, 2007. The locations indicate distance (m) from the observer station. The distance between x and y axis tick marks (500 m) = 0.6 mi.

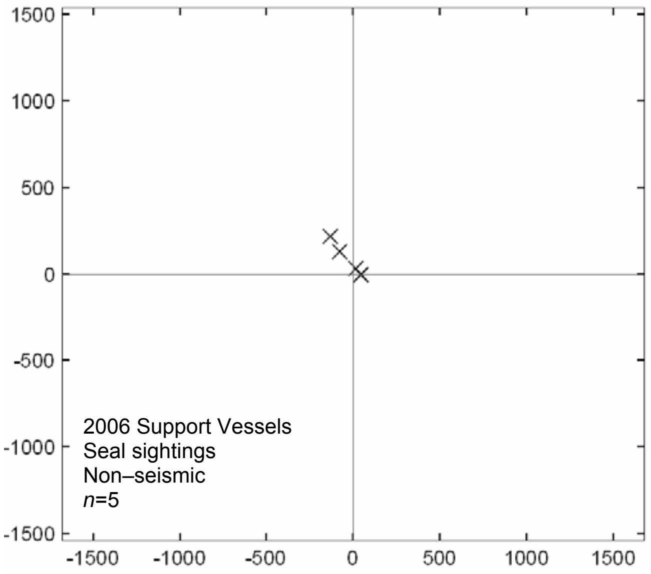

FIGURE 6.18. Relative location of useable non–seismic seal sightings from the support vessels in the Beaufort Sea, 2006. The locations indicate distance (m) from the observer station. The distance between x and y axis tick marks (500 m) = 0.6 mi.

Closest Point of Approach.—As with the cetacean data, the low number of sightings precluded meaningful comparisons of seal CPAs between seismic and non–seismic periods for both the source and support vessels (Table 6.21). The CPA of seals to source vessels during non–seismic periods was less in 2007 (181.1 m or 198 yd) compared to 2006 (253.0 m or 277 yd; Table 6.21). The CPA of seals during non–seismic periods was greater for source vessels than support vessels for both 2006 and 2007. It was not possible to compare seal CPAs to support vessels between 2007 and 2006 due to the low number of sightings in 2006.

TABLE 6.21. Closest observed points of approach (CPA) of seals in water to the airguns of the source vessels or to the observers on the support vessels during seismic and non–seismic periods during the 2006–07 Beaufort Sea surveys.

Effort Category	Mean CPA[a] (m)	s.d.	Range (m)	*n*
2006				
Source Vessels Seismic	-	-	-	-
Source Vessels Non-Seismic	253	198	0-1301	304
Source Vessels Mean	***253***	***198***	***0-1301***	***304***
Support Vessels Seismic	-	-	-	-
Support Vessels Non-Seismic	95	104	5-252	5
Support Vessels Mean	***95***	***104***	***5-252***	***5***
2007				
Source Vessels Seismic	231	196	117-457	3
Source Vessels Non-Seismic	181	136	64-1056	102
Source Vessels Mean	***183***	***137***	***64-1056***	***105***
Support Vessels Seismic	183	155	5-426	14
Support Vessels Non-Seismic	162	176	8-1631	184
Support Vessels Mean	***163***	***175***	***5-1631***	***198***

[a] CPA = *Closest Point of Approach*. For source vessels this value is the marine mammal's closest point of approach to the airgun array, for support vessels this value is the marine mammal's closest point of approach to the MMO/vessel.

- means no data

Distance from Ice Detection Rates.—Seals haul out on and forage near ice, and it was expected that the seal detection rate would vary by proximity to ice. Detection rates of seals as a function of distance from ice for 2006 and 2007 are shown in Tables 6.22 and 6.23. The seal detection rate was higher near the ice edge than in other distance–from–ice categories in 2006, however the amount of useable effort was insufficient in some distance–from–ice categories to make meaningful comparisons.

The amount of ice in the Beaufort Sea in 2007 was reduced compared to 2006 and most seal sightings in 2007 were recorded at distances greater than 20 km from ice (Table 23). Seal detection rates in areas near ice were generally lower in 2007 compared to 2006, however the amount of useable effort was low in many distance-from-ice categories making meaningful comparisons difficult. Overall seal detection rates were greater in 2006 than 2007 which may have been a result of the greater concentration of ice in the project area in 2006.

TABLE 6.22. Number of useable seal sightings, useable effort, and detection rates (# sightings per 1000 km) by distance from ice from all vessels operating in the Beaufort Sea, 2006.

Ice Bin	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Cetaceans			
≥10% Ice Cover	98	1108	88.4
<10% Ice Cover	5	57	87.7
0-5 km from Ice	122	596	204.7
5-10 km from Ice	26	437	59.5
10-15 km from Ice	16	189	84.7
15-20 km from Ice	6	116	51.7
>20 km from Ice	36	1019	35.3

TABLE 6.23. Number of useable seal sightings, useable effort, and detection rates (# sightings per 1000 km) by distance from ice from all vessels operating in the Beaufort Sea, 2007.

Ice Bin	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Cetaceans			
≥10% Ice Cover	18	375	48.0
<10% Ice Cover	11	153	71.9
0-5 km from Ice	12	260	46.2
5-10 km from Ice	9	125	72.0
10-15 km from Ice	4	131	30.5
15-20 km from Ice	3	190	15.8
>20 km from Ice	261	6453	40.4

Detection Rates as a Function of Water Depth.—Seal detection rates as a function of water depth are presented in Tables 6.24 and 6.25. In 2006, all useable seal sightings were recorded at locations where water depth was <50 m (55 yds). The amount of useable survey effort was too low in other water–depth categories to reliably compare seal detection rates in water–depth categories. In 2007 sufficient survey effort was available to compare seal detection rates among water–depth categories, although the amount of survey effort in the ≥200 m depth–category was marginal. Seal detection rates in 2007 were similar within the <50 m and 50–200 m water–depth categories, and declined sharply in deeper waters. This result suggested that seals were most abundant over the continental shelf. However, seals that were foraging offshore may have spent a greater proportion of their time at depth if they were exploiting prey resources deeper in the water column, thereby decreasing the likelihood that they would be detected at the surface by observers. The lower detection rates in the >200 m water–depth category may be a result of seal behavior and marginal survey effort, and does not provide conclusive evidence of lower seal density in deeper waters.

TABLE 6.24. Number of useable seal sightings, useable effort, and detection rates (# sightings per 1000 km) by depth from all vessels operating in the Beaufort Sea, 2006.

Depth Ranges	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Seals			
<50 m	309	3469.7	89.1
50-200 m	0	52.7	0.0
>200 m	0	0.0	0.0

TABLE 6.25. Number of useable seal sightings, useable effort, and detection rates (# sightings per 1000 km) by depth from all vessels operating in the Beaufort Sea, 2007.

Depth Ranges	No. of Sightings	Useable Effort (km)	Detection Rate (Sightings/1000 km)
Seals			
<50 m	274	6360.3	43.1
50-200 m	37	846.0	43.7
>200 m	7	480.4	14.6

Behavior

Movement—Movement was recorded for 94 seal sightings from source vessels during non–seismic periods and one during seismic periods in 2007. The one movement recorded during seismic periods was swimming away from the vessel. Of the sightings recorded during non–seismic periods, 55% were swimming towards the vessel trackline, 34% were swimming in a direction neutral to the vessel's heading, and 11% were swimming away from the vessel's trackline (Fig. 6.19).

During the 2006 season there were 252 seal sightings from the source vessel for which movement was recorded during non–seismic periods (Fig. 6.19). Of these, 46% were swimming away from the vessel's trackline, 24% were swimming towards the vessel's trackline, 22% were traveling in a neutral direction, and 8% showed no movement. No seal movement was recorded from the source vessel during seismic periods in 2006.

There were 101 seal sightings from support vessels with movement records during the 2007 season, all of which occurred during non–seismic periods (Fig. 6.20). Of these, 61% of the animals were moving in a direction neutral relative to the vessel, 25% were swimming away from the vessel, and 14% were swimming toward the vessel. There were also two sightings of seals on ice, one of which was moving towards the vessel, the other away from it.

Movement was recorded for four seal sightings from support vessels in 2006. Of these, one was not moving, two were swimming in a direction neutral to the vessel, and one was swimming towards the vessel.

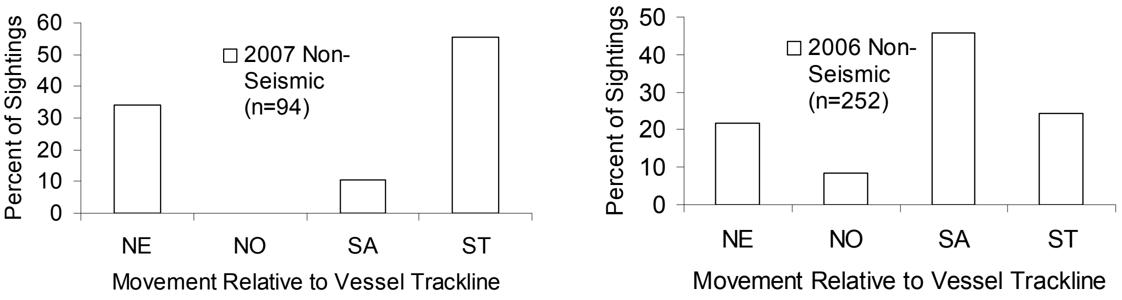

FIGURE 6.19. Percent of movement category relative to source vessels for useable seal sightings by seismic state for 2007 and 2006 Beaufort Sea vessel operations. SA = Swim Away, ST = Swim Toward, NE = Neutral, NO = None.

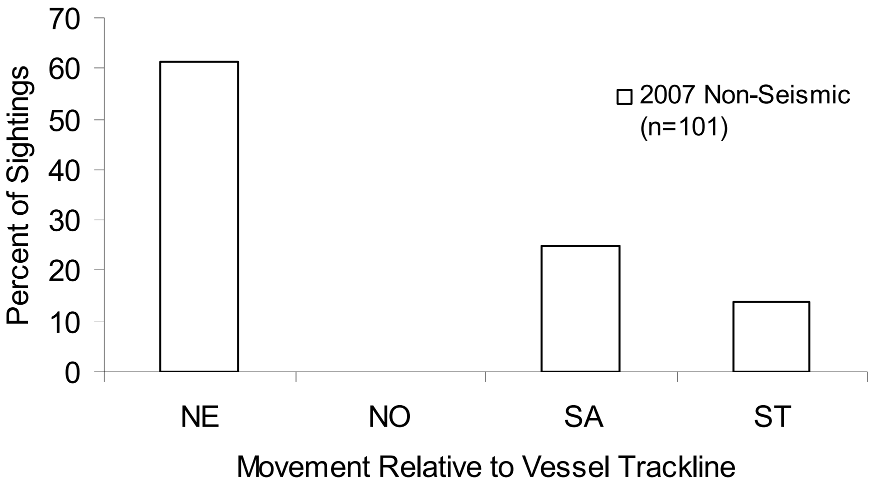

FIGURE 6.20. Percent of movement category relative to support vessels for useable seal group sightings by seismic state for 2007 Beaufort Sea vessel operations. SA = Swim Away, ST = Swim Toward, NE = Neutral, NO = None

Initial Behavior.—There were 105 seal sightings from the source vessels for which behavior was recorded in 2007 (Fig. 6.21). Three of these sightings occurred during seismic survey periods; the remaining 102 occurred during non–seismic periods. Two of the three seals observed during seismic periods were swimming/traveling; the other was observed diving. Of the 102 sightings during non–seismic periods, a majority of the animals (53) were looking at the vessel and most of the remaining animals (44) were recorded as surface active (Fig. 6.21). The sample size during seismic survey activities in 2007 was too low to compare seal behavior during seismic and non–seismic periods.

There were no seal behaviors recorded from source vessels during seismic periods in 2006; during non–seismic periods 304 seal behaviors were recorded (Fig. 6.21). Of the 304 sightings during 2006, most of the animals were observed either looking at the vessel, diving, or swimming/traveling.

Behaviors were recorded for 198 seal sightings from the support vessels during the 2007 season (Fig. 6.22). Of these, 14 occurred during seismic periods and 184 occurred during non–seismic periods. Of the animals observed during seismic operations, most looked at the vessel and the remaining seals were either swimming/traveling or surface active. Although the seismic period sample size was low, the same three behaviors comprised the majority of observations from support vessels during non–seismic periods (Fig. 6.22).

There were an additional 15 sightings of seals on ice recorded from support vessels in 2007. Two of these seals were looking and 13 were resting.

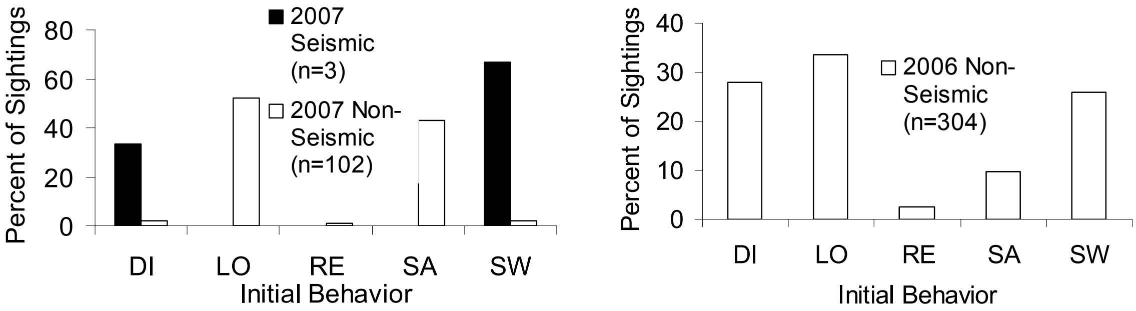

FIGURE 6.21. Initial behavior of seals sighted from source vessels during the 2006 and 2007 Beaufort Sea surveys.

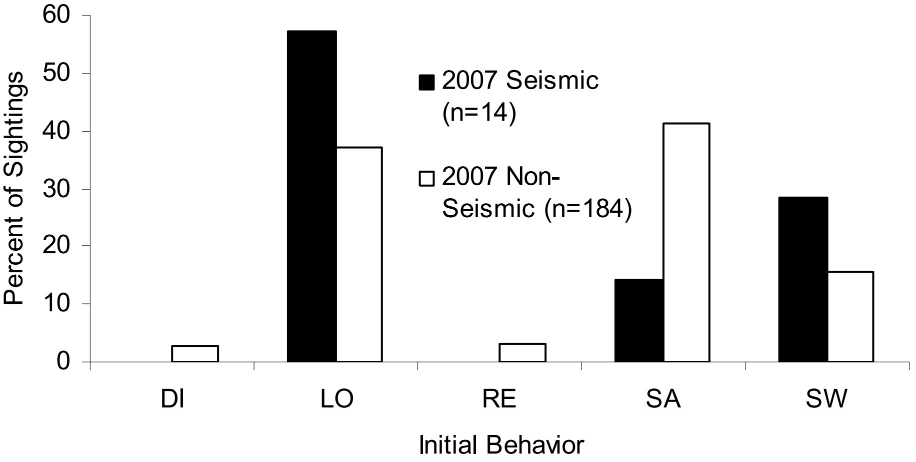

FIGURE 6.22. Initial behavior of seals sighted from support vessels during the 2007 Beaufort Sea surveys.

Reaction Behavior.—Reaction behavior was recorded for 105 seal sightings from source vessels in 2007, three of which were during seismic periods, and 102 during non–seismic periods (Fig. 6.23). Of the three sightings during seismic periods, one animal exhibited no reaction, one animal splashed, and one animal looked at the vessel. During non–seismic periods about half of the animals (50) splashed and just over one–third of animals exhibited no reaction. With so few reaction behaviors recorded during seismic periods, no comparison could be made between seismic and non–seismic periods. Reaction behavior codes available to MMOs can be found in the Chapter 3 *Methods* section.

During 2006, there were 304 sightings of seals from source vessels for which reaction behavior was categorized (Fig. 6.21). Most of the animals either changed direction, looked at the vessel, or exhibited no reaction. All sightings occurred during non–seismic periods.

Of 198 seal sightings from support vessels in the 2007 season with behavioral records, 14 occurred during seismic periods and 184 occurred during non–seismic periods. Six of the 14 seals observed during seismic activity exhibited no reaction, five looked at the vessel, two splashed, and one animal changed its direction markedly (Fig. 6.24). Of the 184 seals observed during non–seismic periods the vast majority of animals either exhibited no reaction or looked at the vessel. One animal observed on ice rushed into the water (Fig. 6.24).

There were only five seal sightings from the support vessels during 2006 for which behavior was recorded, all during non–seismic periods. Two animals did not exhibit any reaction and three looked at the vessel.

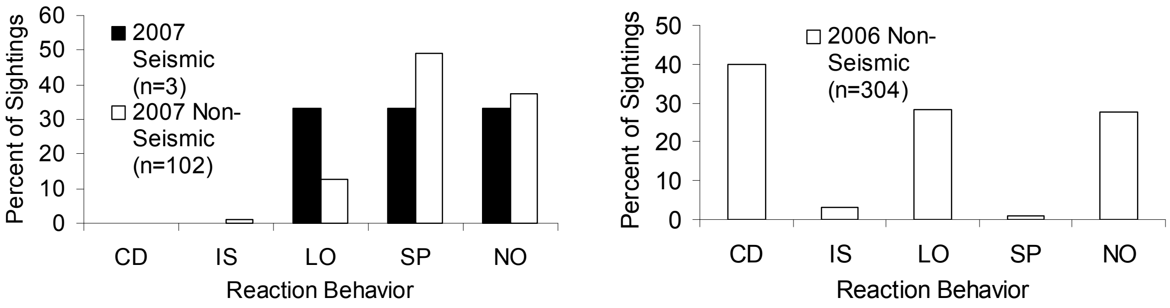

FIGURE 6.23. Reaction behavior of seals sighted from source vessels during the 2006 and 2007 Beaufort Sea surveys.

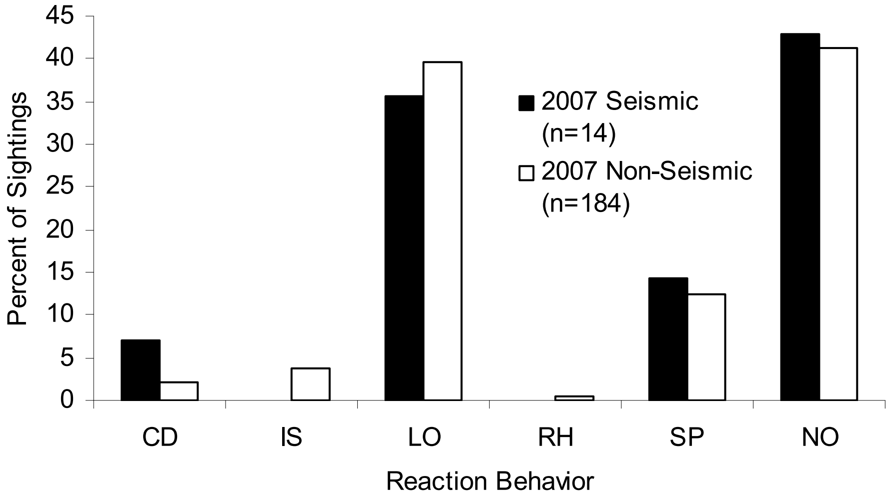

FIGURE 6.24. Reaction behavior of seals sighted from support vessels during the 2007 Beaufort Sea surveys.

Seal Detection Rates Relative to Received Sound Levels

In–water seal detection rates from support vessels were highest in areas where received sound levels were <140 dB in 2007 (Table 6.26). However the amount of useable effort was low for 10–dB rms sound level categories with received sound levels ≥120 dB rms (Table 6.26) making comparisons of detection rates problematic. Survey effort was marginal (slightly >500 km or 311 mi) in areas where received sound levels were 170–179 dB rms, and the associated detection rate was half the detection rate in areas where received levels were <120 dB rms (Table 6.26) There was no useable support vessel pinniped effort in areas with sounds ≥120 dB rms in 2006.

TABLE 6.26. Detection rates of seals in water from the support vessels, divided into 10–dB (re 1 µPa rms) exposure level bins during the Beaufort Sea survey 2007. Detection rates in italics are based on < 500 km (311 mi) of useable effort.

Received Sound Level (dB re1 µPa rms)	Number of Detections	Effort (km)	Detections / 1000 km
<120	35	894.8	39.1
120-129	10	243.1	*41.1*
130-139	9	108.0	*83.3*
140-149	3	286.1	*10.5*
150-159	7	377.9	*18.5*
160-169	0	107.9	*0.0*
170-179	11	531.4	20.7
180-189	0	58.0	*0.0*

Estimated Number of Marine Mammals Potentially Ensonified

Estimates from Direct Observations.—The number of seals directly observed within areas where received sound levels were ≥160 and 180 dB rms provided a minimum estimate of the number of individuals potentially exposed to sounds at these levels. For this analysis the data were not filtered using the usability criteria outlined in the *Methods* section in Chapter 3. Table 6.27 presents the number of seals exposed to received levels ≥160, 170, and 190 dB rms based on direct observations. It is possible that some seals present within these areas were not detected by observers and the estimates likely underestimate the number of individuals ensonified.

During the 2007 season there were six sightings of individual pinnipeds from the *Gilavar* while the airguns were operating. Of these, three occurred while the mitigation gun was firing, two occurred while full array was operating, and one occurred shortly after the beginning of a ramp up sequence. The three animals sighted while the mitigation gun was firing were well outside the 190 dB rms radius for the mitigation source and it was very unlikely that these animals were exposed to sound levels ≥190 dB rms. Both sightings during full array operation resulted in power downs (Table 6.28). In each case the animal dove below the surface within the 190 dB radius before the airgun array was powered down, therefore it is likely that these animals were briefly exposed to sound levels ≥190 dB rms. For the sighting occurring during ramp up, the ramp up sequence had just started and the animal was sighted at 592 m (647 yd) swimming away from the vessel, therefore it is unlikely that this animal was exposed to sound levels ≥190 dB rms.

Two seals were sighted from the *Henry C.* during 2007 shallow hazard survey operations but both animals were well outside the 190 dB radius and it is unlikely that either was exposed to sound levels ≥190 dB rms. No seals were sighted while airguns were operating during the 2006 season, therefore the estimate of the number of seals exposed to ≥190 dB rms based on direct observation was zero.

TABLE 6.27. Total number of seals observed from all vessels within the ≥160, 170 and 190 dB re 1 µPa (rms) radii of seismic airguns in the Beaufort Sea in 2006 and 2007.

Received Sound Exposure Level (dB re 1 µPa rms)	**Individuals**	
	2006	**2007**
≥160	0	20(20)
≥170	0	18(18)
≥190	0	2(2)

TABLE 6.28. List of power downs for pinnipeds sighted within the *Gilavar*'s 190 dB rms safety radius (860 m) during the Beaufort Sea seismic survey (12 Sep – 8 Oct 2007).

Sighting ID	Species	Group Size	Day in 2007 UTC	Water Depth (m)	Reaction to Vessel[a]	Distance (m) to Airguns at First Detection	CPA[b] (m) to Airguns
377	ringed seal	1	18-Sep	27.8	LO	161	161
378	unidentified seal	1	18-Sep	27.7	LO	117	117

[a] Observed reaction of animal to vessel:LO=Look at Vessel

[b] CPA=Closest Point of Approach

Estimates Extrapolated from Density.—Seal density estimates in the Beaufort Sea based on useable effort are shown in Tables 6.29 and 6.30. Density estimates during non–seismic periods in 2007 were higher from support vessels in the summer and from source vessels during fall (Table 6.29). Overall seal density during non–seismic periods was also greater in summer than fall. Estimated seal densities from source and support vessels during seismic periods could not be compared due to the low amount of useable effort during fall from source vessels.

There was little useable effort during seismic periods from either source or support vessels in 2006. Density of spotted/ringed seals during non–seismic periods was much greater than that of bearded seals (Table 6.30). Many seals could not be identified to species and most of these were likely ringed seals given the known abundance of seals in the Beaufort Sea.

TABLE 6.29. Estimated densities of seals in the Alaskan Beaufort Sea during the summer (Jun–Aug) and fall (Sep–Nov) 2007 seasons based on useable effort. Densities are corrected for f(0) and g(0) biases.

		No. individuals / 1000km^2		
		Summer	Fall	
Vessel Type	**Species**	**Non-seismic**	**Seismic**	**Non-seismic**
Source Vessels				
	Bearded Seal	12.6	-	62.8
	Spotted/Ringed Seal	251.8	-	323.0
	Source Vessel Total	**264.4**	**-**	**385.8**
Support Vessels				
	Bearded Seal	85.4	3.7	11.0
	Spotted/Ringed Seal	401.4	50.2	88.2
	Support Vessel Total	**486.8**	**53.9**	**99.2**
All Vessels				
	Bearded Seal	67.3	2.7	23.4
	Spotted/Ringed Seal	364.3	51.5	144.7
	All Vessel Total	**431.6**	**54.1**	**168.1**

TABLE 6.30. Estimated densities of seals in the Alaskan Beaufort Sea during the 2006 season based on all daylight effort. Densities are corrected for f(0) and g(0) biases.

	No. of individuals / 1000km^2	
Species	**Non-Seismic**	**Seismic**
Bearded Seal	15	N/A
Spotted/Ringed Seal	168	N/A
Unidentified Seals	180	N/A

The estimated numbers of seals that may have been exposed to received sounds levels ≥160, 170, 180, and 190 dB (rms) during 2006 and 2007 seismic operations are presented in Tables 6.31 and 6.32. These exposure estimates are from SOI's 2007 90–day report (Funk et al. 2008) and the 2006 Joint Monitoring Program report (Funk et al. 2007). The amount of useable effort from vessels directly involved with seismic operations in the Beaufort Sea in 2007 was not great enough to produce reliable density estimates. As an alternative, all daylight effort and sightings from these vessels were used to calculate the density estimates used in estimating exposures (for details see Funk et al. 2008). Non–seismic estimates represent the number of animals that would have been exposed had they not shown localized avoidance behavior in response to the airguns or the vessels themselves.

In 2007, the numbers of exposures per individual resulting from deep seismic survey activities on the *Gilavar* were greater than the exposure numbers resulting from shallow hazards surveys on the *Henry C.* due to the longer period of seismic activity by the *Gilavar*, and the greater size of the ensonified area of the *Gilavar's* airgun array compared to that of the *Henry C.* (Table 6.31). These numbers were well below the number of "takes" requested by SOI.

TABLE 6.31. Estimated numbers of individual seals exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual during deep seismic and shallow hazards surveys in the Beaufort Sea, 2007. Requested number of takes is also shown. Density estimates are based on all daylight sightings and effort (Funk et al. 2008).

	Based on Non-seismic density		Based on Seismic density		
Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures per Individual**	**Individuals**	**Exposures per Individual**	**Requested Take**
Seismic Surveys					
≥160	149	19	165	19	32,314
≥170	81	11	89	12	
≥180	42	7	47	7	
≥190	27	4	30	4	
Shallow Hazards Surveys					
≥160	63	1.5	19	1.5	771
≥180	4	1.1	1	1.1	
≥190	1	1	0	0	

TABLE 6.32. Estimated numbers of individual seals exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual based on non–seismic data during airgun operations from the *Henry C.* in 2006.

Exposure Level in dB re 1µPa (rms)	Individuals	Exposures per Individual
≥160	148	1.2
≥170	63	1.1
≥180	23	1
≥190	8	1

Pacific Walruses

Only five Pacific walrus sightings (nine individuals) were recorded by MMOs during vessel–based activities in the Beaufort Sea in 2006 and 2007 combined. All five of the Pacific walrus sightings were made from support vessels in 2007. Four sightings (seven individuals) were of walruses in water, and one sighting was of two walruses on ice.

All Pacific walrus sightings were recorded during the fall. One and four sightings were recorded during seismic and non–seismic periods, respectively. There was insufficient data to make meaningful comparisons of walrus detection rates during seismic and non–seismic periods, or for analyses of detection rates as a function of distance from ice or within water–depth categories. The mean Pacific walrus CPA during non–seismic periods was 374 m (409 yd; *n*=3). The CPA for the single walrus sighting during seismic periods was 50 m (55 yd) from a support vessel. Behavioral data were insufficient to make any meaningful comparisons of walrus initial or reaction behaviors.

Based on data from direct observations, no Pacific walruses were detected within areas where received levels were ≥180 dB (rms). One sighting of a cow/calf pair was recorded from a support vessel where received levels were ≥170 dB (rms), and two sightings of three individuals were recorded where received sound levels were ≥150 dB (rms). Other walrus sightings were of animals in areas where received levels were <120 dB (rms).

Based on walrus densities estimated during seismic periods, one Pacific walrus may have been exposed to received levels of ≥180 and 190 dB (rms) during seismic survey activities in the Beaufort Sea in 2007 (Table 6.33). Seven walruses were potentially exposed to received sound levels ≥160 dB (rms).

TABLE 6.33. Estimated numbers of individual Pacific walruses exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual within the Beaufort Sea during the 2007 season.

	A. Based on Non-seismic density		**B. Based on Seismic density**	
Exposure level in dB re 1µPa (rms)	**Individuals**	**Exposures per Individual**	**Individuals**	**Exposures per Individual**
Pacific Walrus				
≥160	1	10	3	18
≥170	0	0	2	9
≥180	0	0	1	5
≥190	0	0	1	2

Polar Bears

Sightings

Total Sightings.—There were three sightings of four individual polar bears in 2006, compared to eight sightings of 14 bears in 2007 (Table 6.34). One of the 2007 sightings was of an adult with two juveniles on Cross Island. All useable polar bear sightings except one were recorded from the *Henry C.* which often anchored in sheltered areas to avoid rough weather, increasing the chances of sighting polar bears near islands. Due to the low number of polar bear sightings, both in–water and on–ice or land sightings were pooled in later analyses.

TABLE 6.34. Numbers of useable sightings (number of individuals) of polar bears in water or on ice or land from the source and support vessels in the Beaufort Sea (2006 and 2007).

	Source Vessel(s)		**Support Vessels**		***Total All Vessels***	
Species	**2006**	**2007**	**2006**	**2007**	***2006***	***2007***
Polar Bears in Water	2 (3)	0	0	0	***2 (3)***	***0***
Polar Bears on Ice or Land	1 (1)	7 (11)	0	1 (3)	***1 (1)***	***8 (14)***
Total Polar Bears	***3 (4)***	***7 (11)***	***0***	***1 (3)***	**3 (4)**	**8 (14)**

Detection Rates by Season.—Detection rates of polar bears from source vessels were higher in the summer (Jul–Aug) than the fall (Sep–Oct) in both 2006 and 2007, but the 2007 useable summer effort from the source vessels was low (Table 6.35). Higher polar bear detection rates were recorded from the source vessels than the support vessels during summer and fall in the Beaufort Sea in 2007 (Table 6.35). The relatively high polar bear detection rate in summer 2007 (19.1 detection/1000km) should be viewed with caution due to the low amount of useable effort. Fall detection rates were similar for source vessels between 2006 and 2007, and the 2007 fall detection rate was slightly higher from source vessels compared to support vessels (Table 6.35).

TABLE 6.35. Detection rates (# groups per 1000 km) for useable polar bear sightings during summer and fall from ***(A)*** source vessels, and ***(B)*** support vessels in the Beaufort Sea (2006 and 2007). Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

	2006			2007		
Season	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**
A. Source Vessel(s)						
Jul–Aug	2	1765.4	1.1	6	314.0	*19.1*
Sep–Oct	1	1664.2	0.6	1	1597.9	0.6
B. Support Vessels						
Jul–Aug	0	57.2	*0.0*	0	1214.6	0.0
Sep–Oct	0	35.6	*0.0*	1	4561.6	0.2

Detection Rates by Seismic State.—All polar bear sightings occurred during non–seismic periods, and polar bear detection rates were higher from source than the support vessels in the Beaufort Sea in 2006 and 2007 (Table 6.36). The low number of polar bear sightings and generally low amount of useable effort during seismic periods in 2006 and 2007 (Table 6.36) precludes meaningful comparisons of polar bear detection rates during seismic and non–seismic periods. For a break–down of in–water versus on–ice or land polar bear sightings by seismic state, see Appendix Table C.9.

TABLE 6.36. Detection rates (# groups per 1000 km) for useable polar bear sightings during seismic and non–seismic periods from ***(A)*** source vessels, and ***(B)*** support vessels in the Beaufort Sea (2006 and 2007). Detection rates in italics are based on less than 500 km useable effort and should be viewed with caution.

	2006			2007		
Seismic State	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**	**No. of Sightings**	**Useable Effort (km)**	**Detection Rate (No./1000 km)**
A. Source Vessel(s)						
Seismic	0	59.3	*0.0*	0	334.3	*0.0*
Non-Seismic	3	3370.3	0.9	7	1576.3	4.4
B. Support Vessels						
Seismic	0	0.0	N/A	0	843.2	0.0
Non-Seismic	0	92.8	*0.0*	1	4933.0	0.2

Note: N/A means Not Applicable.

Distribution

Initial Sightings Relative to Vessels.—There were eleven useable polar bear sightings from all vessels combined during 2006 and 2007 combined; the bearing and distance from the vessel to two of these sightings was recorded (Fig. 6.25). Both sightings were made from the source vessel during non–seismic periods in 2006. Neither sighting was within the vessel's 180dB radius; one polar bear was to the side of the vessel, the other was to the side and behind the vessel.

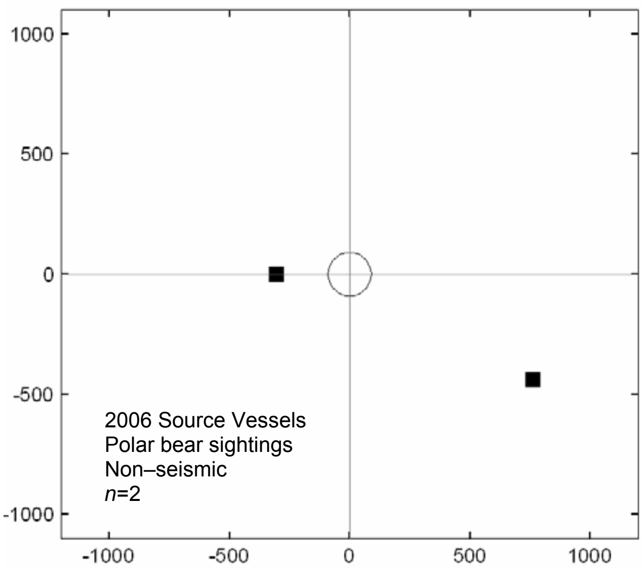

FIGURE 6.25. Relative location of useable non–seismic polar bear sightings from the source vessel in the Beaufort Sea, 2006. The vessel's 180dB radius (51m or 55.8 yd) is shown. The sighting locations indicate distance (m) from the airgun array located 300 m (328 yd) aft of the observer station. The distance between x and y axis tick marks (500 m) = 0.3 mi.

Closest Point of Approach.—The CPA of two polar bear sightings in water, both observed from source vessels during non–seismic periods in 2007, were used in CPA analyses. No comparisons were possible between years, vessel type, or seismic activity. CPAs for the two polar bear sightings were 305 and 877 m (334 and 959 yd).

Distance from Ice Detection Rates.— For combined observations in 2006 and 2007, only three polar bear sightings occurred within 20 km of ice. In 2006, one sighting occurred in >10% ice and one occurred 0–5 km (0–3 mi) from the ice edge. The small sample size precluded a meaningful analysis of polar bear detection rates as a function of distance from ice.

Water Depth Detection Rates.—All 11 polar bear sightings recorded in 2006 and 2007 were recorded in areas with water depth <50 m (55 yds). In 2006, this shallow depth category was the only one with >500 km (311 mi) of useable effort, however in 2007 all depth categories were represented by reasonable amounts of effort (Table 6.24 and 6.25 above).

Behavior

Movement.—Movement was recorded for three polar bear sightings from source vessels during the 2007 season; all three were on ice and not exposed to seismic sounds. One animal was traveling in a direction neutral to the vessel; the other two were headed away from the vessel.

Only three sightings of polar bears in water were made from the source vessels, all during non–seismic periods in 2006. One animal was not moving in any particular direction, the other two animals were headed away from the vessel. Given the small number of sightings, no conclusions can be drawn from these data. There were no sightings of polar bears with movement records made from the support vessels.

Initial Behavior.—Behavior records were recorded for seven polar bear sightings from the source vessels during the 2007 season. All animals were observed on ice or land during non–seismic periods. Five of the animals were looking and two were walking. There were two sightings of polar bears from the source vessels during 2006 for which there are behavioral records; both animals were observed swimming.

Behavior was recorded for only one polar bear sighting from the support vessels. This was a sighting of a bear walking on ice during the 2007 season.

Reaction Behavior.—None of the seven polar bears sighted from the source vessels during the 2007 season for which behavioral data were recorded exhibited a reaction behavior. One animal sighted during non–seismic periods in the 2006 season changed direction while swimming.

The one polar bear sighted from support vessels during 2007 for which there was a behavior record did not react to the vessel. There were no behavioral records for polar bears sighted from the support vessels during the 2006 season.

Polar Bear Detection Rates Relative to Received Sound Levels

There were no useable support vessel sightings of polar bears in water in either 2006 or 2007 during periods of seismic survey activities in the Beaufort Sea. This precluded analyses of polar bear detection rates as a function of received sound levels.

Estimated Number of Marine Mammals Potentially Ensonified

Estimates from Direct Observations.—No polar bears were sighted from or near the *Gilavar* during 2007 or from the *Henry C.* during either 2006 or 2007. Thus there were no exposures of polar bears to received sound levels ≥190 dB (rms) based on direct observations.

Estimates Extrapolated from Density.—Estimates of the number of polar bears exposed to various received sound levels during the *Gilavar's* 2007 seismic survey are shown in Table 6.37. These values are from SOI's 2007 operations 90–day report (Funk et al. 2008). The amount of useable effort from vessels directly involved with seismic operations in the Beaufort Sea in 2007 was not sufficient to produce reliable density estimates. As an alternative, all daylight effort and sightings from these vessels were used to calculate the density estimates used in estimating exposures (for details see Funk et al. 2008). Non–seismic estimates represent the number of animals that would have been exposed had they not shown localized avoidance behavior in response to the airguns or the vessels themselves. It was estimated that no polar bears were exposed to seismic sounds ≥180 dB rms during the 2006 or 2007 shallow hazards surveys. Because of a lack of useable effort, these estimates are based on densities calculated using all daylight effort.

TABLE 6.37. Estimated numbers of individual polar bears exposed to received sound levels ≥160, 170, 180, and 190 dB (rms) and average number of exposures per individual within the Beaufort Sea during the 2007 season based on non–seismic data.

Exposure Level in dB re 1µPa (rms)	Individuals	Exposures per Individual
≥160	2	16
≥170	1	10
≥180	0	0
≥190	0	0

DISCUSSION

In 2006 and 2007, less than 10% of useable effort occurred during seismic periods. For the two years combined, most of the data during periods of seismic survey activity were collected in 2007. In 2006, persistent ice in the Alaskan Beaufort Sea precluded deep seismic surveys and seismic survey activity was confined to ~12 hours of airgun operation during shallow hazards surveys. The airgun array used in 2006 was comprised of two 70–in^3 airguns (total volume of 140 in^3), although a four–airgun array (total volume of 280 in^3) was used during measurements of underwater sound propagation. In contrast, ice cleared rapidly in the Alaskan Beaufort Sea in 2007 allowing SOI to conduct deep seismic survey operations and shallow hazards surveys in fall. However, the lack of ice may have contributed to higher sea conditions causing many of the data to fall outside of the usability criteria ($\text{Bf} \leq 5$). Because few useable data were collected during seismic periods, most comparisons of data between seismic and non–seismic periods to identify potential effects of seismic activity on marine mammals in the Alaskan Beaufort Sea should be viewed with caution.

Overall marine mammal detection rates were slightly higher in 2007 compared to 2006, with the greatest difference due to higher numbers of cetaceans. There have been few vessel–based surveys and few cetacean sightings during vessel–based activities in the Beaufort Sea. Miller et al. (1998) reported one vessel–based bowhead whale sighting during Ocean Bottom Cable (OBC) surveys in relatively nearshore areas between Northstar and Flaxman Island in 1996 and 1997. No cetaceans were recorded during similar surveys in 2000 and 2001 (Richardson 2001; Richardson and Lawson 2002). Coltrane (2002) reported a single gray whale sighting during shallow hazards surveys near Northstar Island in 2001. More recently Green et al. (2007) reported bowhead, gray, and humpback whale sightings during barge transits near Smith Bay east of Barrow.

In the current study most cetacean sightings were recorded in 2007 and bowhead whale was the most frequently sighted cetacean during vessel–based surveys in the Beaufort Sea. The increased cetacean detection rate in 2007 may have been due to reduced ice conditions and vessel operation near the southern portion of the bowhead migration corridor. The bowhead whale migration corridor occurs closer to shore during years of light and moderate ice conditions than during years of heavy ice conditions (Moore et al. 2000; Treacy et al. 2006), and the reduced amount of ice cover in 2007 compared to 2006 may have resulted in more bowheads moving through the project area in 2007.

No cetacean behavior observed from vessels operating in the Beaufort Sea in 2007 was recorded as feeding. However, bowhead whale behavior observed during aerial surveys in the Beaufort Sea was commonly recorded as feeding well into Sep in 2007 (Chapter 7). Whales observed from vessels may have been feeding, but vessels did not follow whales for long periods and activities of whales were less easily determined from vessels than aircraft. Most bowhead whale feeding probably occurs during the summer in the Canadian Beaufort Sea although bowhead feeding has been reported at a number of locations in the Alaskan Beaufort Sea during late summer and fall (Landino et al. 1994; Miller et al. 1999, 2002; Würsig et al. 2002; Lowry et al. 2004).

In 2007, seven individual cetaceans (4 sightings) were potentially exposed to seismic sounds ≥180 dB (rms); of these, observers recorded only one instance when seismic activity elicited a detectable reaction (splashing). However, cetaceans also splashed in reaction to vessels during non–seismic periods on two occasions. No cetaceans were observed during seismic activity in the Beaufort Sea in 2006.

Seals were the most common marine mammals encountered during vessel–based surveys in the Beaufort Sea in 2006 and 2007. When data were sufficient to compare seasonal seal detection rates, the detection rates were higher in fall 2006 (based on observations from the source vessel) and in the summer in 2007 (based on observations from support vessels). The difference in seasonal seal detection rates between years may have been related to differences in ice conditions. The ice receded earlier in the year in 2007 and ice coverage in 2006 was much greater than during 2007.

Seal detection rates for combined 2006 and 2007 data ranged from 40.3 to 90.2 seals/1000 km during non–seismic periods. The seal detection rate during seismic periods was 16.6 seals/1000 km from support vessels in 2007. Useable seismic data were insufficient to calculate meaningful seal detection rates in 2006 or from source vessels in 2007. The available data suggest seal avoidance of seismic survey activity. No useable seal sightings were made from support vessels in areas with ensonified levels ≥180 dB (rms). Harris et al. (2001) reported nearly identical seal sighting rates during vessel–based seismic survey activity in the Beaufort Sea during periods with no airgun activity, a single airgun firing, and with the full array firing. However the airgun array used during the OBC seismic survey activities described by Harris et al. (2001) was much smaller (1320 in^3) than the array deployed from the *Gilavar* (3147 in^3).

Estimated densities based on seal sightings from source and support vessels in 2007 ranged from 54.1 seals/1000 km^2 during seismic periods to 431.6 seals/1000 km^2 during non–seismic periods. Seal densities estimated during other vessel–based survey activities in the Beaufort Sea ranged from ~51 to 300 seals/1000 km^2 from 1996 to 2001 (Harris et al. 1997, 1998; Lawson and Moulton 1999; Moulton and Lawson 2000, 2001, 2002). Much higher seal densities ranging from ~490 to 2940 seals/ km^2 were reported during aerial surveys in the Beaufort Sea (e.g., Frost and Lowry 1999; Moulton et al. 2002), however the aerial surveys were conducted earlier in the year when seals were recorded at breathing holes in the ice and the data may not be comparable to the current vessel–based data.

Two seals were observed within areas ensonified to ≥190 dB (rms) in 2007, and no seals were observed while airguns were operating in 2006. The number of individual seals exposed to received sound levels ≥190 dB (rms) in 2007 based on seal density estimates ranged from 27 to 30 with an average of four exposures per individual seal. The scope of the seismic survey activity was reduced in 2006 compared to 2007 and only eight seals were estimated to have been exposed to sound levels ≥190 dB (rms) in 2006. These levels of seal exposure were far less than the number of “takes” requested by SOI.

Pacific walruses are fairly abundant in the Chukchi Sea but are uncommon in the Alaskan Beaufort Sea. This is likely related to the availability of food and feeding habitat. Pacific walruses feed primarily on benthic invertebrates in relatively shallow water (Reeves et al. 2002), and the Chukchi Sea provides extensive feeding habitat. The concentration of benthic biomass is reduced in the Beaufort Sea compared to the Chukchi Sea (Dunton et al. 2005), and the continental shelf drops off more rapidly in the Beaufort than in the Chukchi Sea reducing the availability of feeding habitat. Only five sightings of Pacific walruses were recorded during vessel–based activities in the Beaufort Sea in 2007, and no walrus sightings were recorded in 2006.

Although polar bears are not uncommon in the Alaskan Beaufort Sea, they are not abundant, especially in ice–free waters. A greater number of polar bear sightings was recorded in 2007 compared to 2006, and this may be related to the reduced ice coverage in 2007. The *Henry C.* frequently anchored near barrier islands during periods of rough sea conditions and the lack of sea ice in 2007 may have caused polar bears to concentrate on the barrier islands.

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7. BEAUFORT SEA AERIAL MARINE MAMMAL MONITORING PROGRAM[1]

Introduction

Aerial marine mammal monitoring programs were conducted in the fall of 2006 and 2007 in support of seismic exploration activities within the Alaskan Beaufort Sea. Surveys were flown from late Aug through early Oct in 2007 and from late Aug through late Sep in 2006 with the goal of obtaining detailed data on the occurrence, distribution, and movements of marine mammals, particularly bowhead whales, within about 50 km (31 mi) to the east and 70 km (43 mi) to the west of seismic survey activities. In addition, the IHA issued to SOI by NMFS required aerial monitoring of the 120 dB re 1 µPa (rms) zone for bowhead whale cow/calf pairs during normal survey activity. If four or more bowhead cow/calf pairs were sighted within the 120 dB (rms) isopleth, the aerial survey crew was required to notify the MMO on watch aboard the seismic vessel.

Objectives

The objectives of the aerial survey program were

- to advise operating vessels as to the presence of marine mammals in the general area of operation and, in so doing, meet requirements of the IHA issued by NMFS;
- to collect and report data on the distribution, abundance, orientation, and activity of marine mammals near the seismic operations with special emphasis on migrating bowhead whales;
- to support regulatory reporting related to the estimation of impacts of seismic operations on marine mammals;
- to monitor accessibility of bowhead whales to Inupiat hunters; and
- to document the extent, duration, and location of any bowhead whale deflections in response to seismic activities.

Methods

Study Area

Transects flown in 2007.—Three survey grids were flown in 2007; one grid was designed to monitor marine mammal distribution near seismic operations of the *Henry C.* in Harrison Bay at the Phoenix prospect (Figure 7.1). Transects ranged in length from 60–76 km (37–47 mi) and covered an area of 9477 km^2 (3659 mi^2). The other two grids were designed to monitor marine mammal distributions during operations at the Sivulliq prospect in Camden Bay. The first Camden Bay grid design (Figure 7.1) was based on the 120 dB re 1 µPa (rms) radius as estimated before the field season. Transects ranged in length from 79–103 km (49–64 mi) and covered an area of 15,565 km^2 (6010 mi^2). The second Camden Bay grid was designed after measurements of the 120 dB radius were obtained during sound source measurements at the start of seismic activity (Figure 7.1). Transects ranged in length from 87–146 km (54–91 mi) and covered an area of 23,962 km^2 (9252mi^2).

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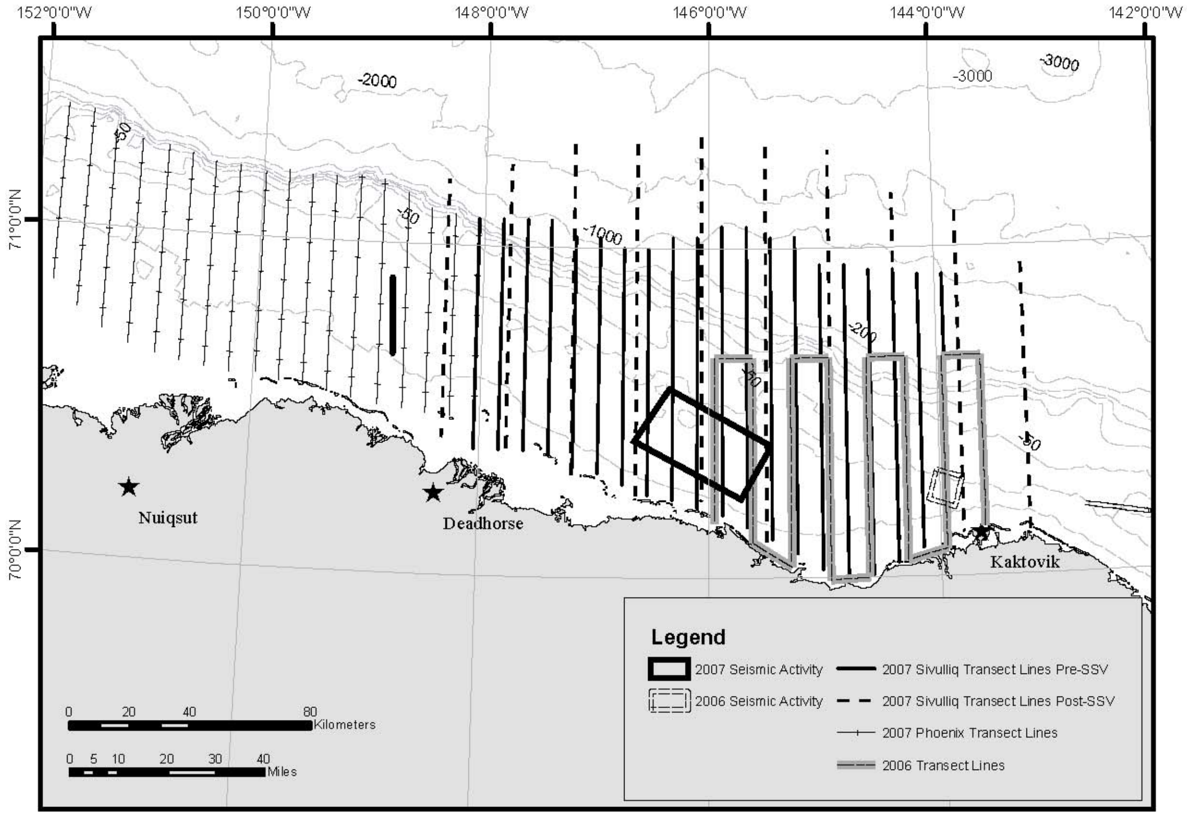


FIGURE 7.1. Transect lines flown in the Alaskan Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007.

Transects flown in 2006.—A series of eight north–south transect lines was established to monitor marine mammal distribution in Camden Bay (Figure 7.1) in support of shallow hazards surveys in 2006. Transect lengths varied from approximately 51–74 km (32–46 mi) and survey area covered approximately 5658 km^2 (2185 mi^2).

Survey Procedures

Surveys in both 2006 and 2007 were flown in Twin Otter aircraft, though surveys during the first month of effort in 2006 were conducted with an Aero Commander provided by Commander Northwest. In 2006, a standard Twin Otter with bubble windows at observer positions was provided by ERA Aviation of Anchorage and used as the survey platform. Inverters were installed to provide 110 V AC power for operation of computers and an auxiliary GPS unit. The Twin Otter used in 2007 was supplied by Bald Mountain Air, and was specially modified for survey work. Modifications included upgraded engines, a STOL kit to allow safer flight at low speeds, wing–tip fuel tanks, multiple GPS navigation systems, bubble windows for primary observers, and 110 V AC power for survey equipment.

Surveys were conducted at altitudes of 305–457 m (1000–1500 ft) above sea level and at a groundspeed of approximately 120 knots. Fuel capacity and weather conditions determined flight length. "No–fly" zones were established around coastal villages and hunting areas during hunting seasons. These procedures were implemented to provide as much coverage of the survey area as possible while:

- minimizing the potential for aircraft disturbance to whales in the whaling area; and
- maximizing the probability the aircraft would be at high altitude (457 m; 1500 ft) if whalers were encountered.

Two primary observers sat at bubble windows on opposite sides of the aircraft and searched the water visible through the bubble windows with the unaided eye, concentrating on the area within 1.2 km (0.74 mi) of the aircraft. When a marine mammal was sighted, the observers dictated into a digital recorder the species, number of individuals, size/sex/and age class when determinable, activity, heading, swimming speed category (if traveling), ice conditions (percentage), and inclinometer reading. The inclinometer reading was recorded when the animal's location was 90° to the side of the aircraft track, allowing calculation of lateral distance from the aircraft trackline. In addition, each observer recorded the time, sightability (subjectively classified as excellent, good, moderately impaired, seriously impaired or impossible), sea conditions (Beaufort wind force), ice cover (percentage) and sun glare (none, little, moderate, or severe) at 2–min intervals along transects, and at the end of each transect. This provided data in units suitable for statistical summaries and analyses of effects of these variables (and position relative to seismic vessel) on the probability of detecting animals (see Davis et al. 1982; Miller et al. 1999; Thomas et al. 2002).

Data Recording

A third observer's primary duty was to enter data into a laptop computer, with a secondary duty of searching for marine mammals during periods when data entry was not necessary. Transect start and stop information, time period markers, number and species sighted, and sighting locations were entered into a GPS–linked laptop computer by the third observer. These data and additional details about environmental variables and each sighting were simultaneously recorded on digital recorders for backup, validation, and later entry into the sightings database. At the start of each transect, a designated primary observer recorded the transect start time and position, ceiling height (ft), cloud cover (in 10ths), wind speed (knots), and outside air temperature (°C) onto a digital voice recorder. The laptop computer ran Garmin Mapsource (ver 6.9) position logging software in 2006 and NRoute software in 2007. These programs were used to automatically record time and aircraft position at pre–selected intervals (typically at two seconds for straight–line transect surveys) as they were obtained.

Analyses of Aerial Survey Data

Useable data.—Environmental factors, such as sea conditions and glare, can impact an observer's ability to see marine mammals during aerial surveys and hence bias results. To minimize bias, environmental data were used to classify sightings data as "useable" or "non–useable" for quantitative analyses. Cetacean sightings were considered useable when the following criteria were met: Beaufort wind force of 4 (winds 20–30 km/h or 11–16 kts) or less, glare covering 30% or less of the viewing field, and overall sightability described as excellent to moderately impaired. Useable pinniped sightings were calculated similarly except that Beaufort wind force of 2 (winds 7–11 km/hr or 11–15 kts) or less was required.

Seismic State.—Seismic activities at the time each aerial survey was flown were determined from data compiled by marine mammal observers on seismic source vessels. In order to assess the impact of seismic activity on sighting rates, data were grouped into bins corresponding to the seismic state at time of sighting. Sightings made while guns were active (including periods of ramp–up and mitigation gun firing) and up to three minutes after shut down were considered "seismic". Sightings made from three minutes to 24 hours after shut down were considered "post–seismic". All other times were considered "non–seismic". The post–seismic category represented the refractory period during which mammals impacted by seismic activities return to normal behavior and hence was analyzed separately. The slow speeds at which bowheads usually travel (3.9–4.5 km/h or 2.1–2.4 kts: Rugh 1990; Richardson et al. 1995b; Koski et al. 2002) make 24 hours an appropriate span of time to allow for their distribution and behavior to return to normalcy following exposure to seismic and other exploration and production activities.

Mapping.—All useable sightings made during aerial surveys were mapped and color coded to indicate seismic state at the time of sighting. Green symbols indicate non–seismic sightings, yellow symbols indicate seismic sightings and black symbols indicate post–seismic sightings. Each symbol represents one sighting, regardless of the number of individuals recorded during that sighting.

Spatial differences.—Differences in both onshore–offshore and west–to–east distribution of marine mammals relative to seismic activity were of interest. In order to assess onshore–offshore distribution of bowheads, effort was assessed by 5–km distance from shore bins, with the "0–km from shore" line consisting of a rough arc along the barrier islands. Sighting rates were computed within each of these bins and statistically compared. To assess changes in west–to–east distribution, the 2007 survey area was divided into three sub–areas: west, central, and east. The central area included the active seismic survey areas and extended from approximately 150°26'W to 149°19'W for Harrison Bay and 146°24'W to 144° 27'W for Camden Bay. The west and east areas were located to the west and east, respectively, of the central area.

Distribution Relative to Center of the Seismic Survey Area.—All sightings made during seismic survey activity were in Camden Bay, so no data from Harrison Bay could be used in determining relative distance of sightings from the center of the seismic survey area. This analysis was performed by plotting the Sivulliq prospect coordinates with ArcView software and estimating the geographical center with the measure tool. Sightings were then plotted and the measure tool used to determine distances of sightings from the center point of the prospect.

Analysis of 2006 data.—Raw data from the 2006 aerial survey program (Thomas et al. 2007) were reanalyzed by applying the 2007 usability criteria for between–year comparison. Environmental conditions in 2006 were very different from those in 2007 and, as such, data were not pooled for analysis. In addition, all data from 2006 were non–seismic so no comparison of reactions to seismic activity could be made between years.

Determination of Estimated Take by Harassment.—Aerial survey densities used to estimate "takes" by harassment were calculated using DISTANCE software (Thomas et al. 2007). Densities were calculated for each survey individually, and then a weighted average was taken for surveys that were flown during a contiguous stretch of seismic activity. The weighted average density for each period was used to calculate "takes" during that contiguous period.

Results and Discussion

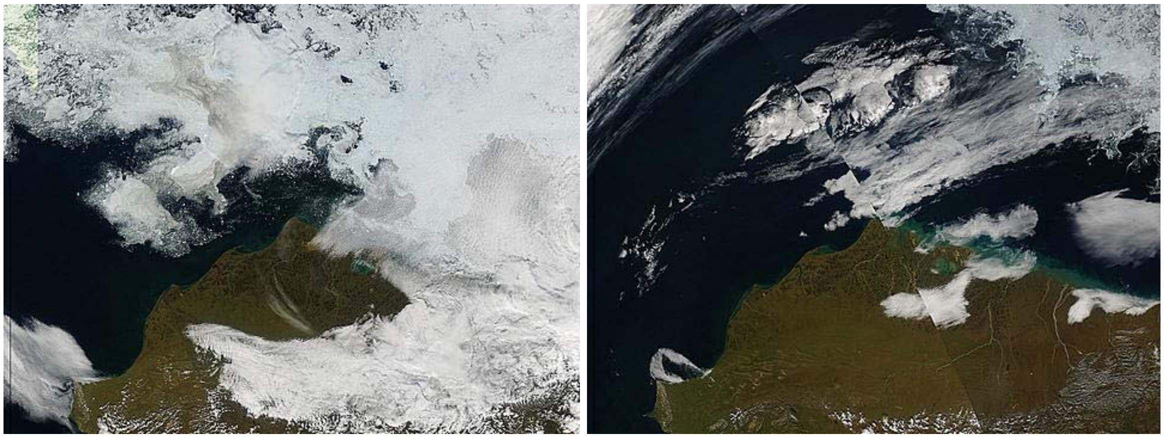
Ice cover

Ice cover in 2007.—Ice coverage was reduced in 2007 compared to 2006 (Figure 7.2; MODIS 2007) and no pack ice was encountered during surveys in 2007. However, thin layers of new ice started to form in nearshore areas on 7–8 Oct.

Ice cover in 2006.—On average, ice cover in 2006 was 1.8 times greater than that in 2007 (see Introduction, Chapter 6). In addition, pack ice was continuously present in parts of the study area from late Aug through Sep.

Survey effort

Effort in 2007.—Aerial surveys were flown over the central Alaskan Beaufort Sea from 22 Aug through 8 Oct 2007 and a total of 7380 km (4586 mi) of useable effort was obtained. Survey effort and bowhead and beluga whale sighting information are summarized in Table 7.1.



24 Aug 2006 24 Aug 2007

FIGURE 7.2. Sea ice extent within the Alaskan Beaufort Sea on 24 Aug 2006 and 2007. Images from the Moderate Resolution Imaging Spectroradiometer (MODIS) website http://rapidfire.sci.gsfc.nasa.gov/subsets/?AERONET_Barrow/.

Three surveys (1498 km or 931 mi of useable effort) were completed within Harrison Bay in support of shallow hazards surveys conducted by the *Henry C.* and an additional 10 surveys (5882 km or 3655 mi of useable effort) were conducted in support of deep seismic survey work by the *Gilavar* in Camden Bay (Appendix Figure D.1). Approximately half of the aerial survey effort in Camden Bay was conducted during non–seismic periods (3897 km; 2421 mi). The remaining survey effort was divided evenly between seismic and post-seismic periods (approximately 1737 km (1079 mi) and 1747 km (1086 mi; Appendix Figure D.2), respectively. Poor weather (i.e., low ceilings and high winds) and dense smoke from wildfires prevented surveying on numerous days (Appendix Figures D.3 and D.4).

Effort in 2006.—In 2006, surveys were conducted on nine days (ten flights) from 26 Aug through 24 Sep. Useable survey effort consisted of 2832 km (1759 mi) of trackline. The final survey grid was flown (Figure 7.1) prior to the start of seismic operations to search for bowhead cow/calf pairs within the 120 dB re 1 ųPa (rms) radius. Survey effort and sighting rates are summarized in Table 7.1.

TABLE 7.1 Summary of useable aerial survey effort and sighting rates in the central Alaskan Beaufort Sea, 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Sighting rates were based on useable sightings and effort. Values in parentheses were based on less than 500 km (311 mi) of effort. Sighting rates were not calculated when effort was less than 250 km (155 mi).

Year	Date	Survey No.	Effort (km)	Percent of Survey Area	Bowhead Whale				Beluga Whale			
					Sightings	Individuals	Sightings/ 1000 km	Individuals/ 1000 km	Sightings	Individuals	Sightings/ 1000 km	Individuals/ 1000 km
2006												
	26 Aug	1	449	85	(3)	(3)	(6.7)	(6.7)	(1)	(1)	(2.2)	(2.2)
	3 Sep	2	463	86	(3)	(3)	(6.5)	(6.5)	(0)	(0)	(0)	(0)
	4 Sep	3	477	90	(7)	(11)	(14.7)	(23.1)	(0)	(0)	(0)	(0)
	6 Sep	4	498	94	(15)	(21)	(30.1)	(42.2)	(14)	(44)	(28.1)	(88.4)
	12 Sep	5	83	16	(1)	(1)	NC	NC	(0)	(0)	NC	NC
	13 Sep	6	397	75	(2)	(4)	(5.0)	(10.1)	(3)	(10)	(7.6)	(25.2)
	14 Sep	7	303	57	(1)	(1)	(3.3)	(3.3)	(1)	(2)	(3.3)	(6.6)
	23 Sep	8	29	6	(1)	(1)	NC	NC	(0)	(0)	NC	NC
	24 Sep	9	132	25	(0)	(0)	NC	NC	(0)	(0)	NC	NC
	Total		**2831**	**59**	**33**	**45**	**12.2**	**15.3**	**19**	**57**	**10.3**	**30.6**
2007												
	22 Aug	1	869	69	4	5	4.6	5.8	1	13	1.2	15.0
	24 Aug	2	290	23	(4)	(4)	(13.8)	(13.8)	(0)	(0)	(0.0)	(0.0)
	3 Sep	3	339	27	(5)	(5)	(14.7)	(14.7)	(0)	(0)	(0.0)	(0.0)
	10 Sep	4	882	49	16	19	18.1	21.5	0	0	0.0	0.0
	11 Sep	4,5	1074	59	20	26	18.6	24.2	30	48	27.9	44.7
	14 Sep	5	458	25	(8)	(15)	(17.5)	(32.8)	(0)	(0)	(0.0)	(0.0)
	18 Sep	6	708	39	14	17	19.8	24.0	0	0	0.0	0.0
	19 Sep	6	7	0	(0)	(0)	NC	NC	(0)	(0)	NC	NC
	20 Sep	7	488	27	(4)	(4)	(8.2)	(8.2)	(0)	(0)	(0.0)	(0.0)
	21 Sep	8	1178	65	6	18	5.1	15.3	0	0	0.0	0.0
	26 Sep	9	51	3	(0)	(0)	NC	NC	(0)	(0)	NC	NC
	30 Sep	10	241	13	(3)	(5)	NC	NC	(0)	(0)	NC	NC
	2 Oct	11	92	8	(0)	(0)	NC	NC	(0)	(0)	NC	NC
	3 Oct	11,12	552	48	1	1	1.8	1.8	0	0	0.0	0.0
	7 Oct	13	134	12	(0)	(0)	NC	NC	(0)	(0)	NC	NC
	8 Oct	13	18	2	(0)	(0)	NC	NC	(0)	(0)	NC	NC
	Total		**7380**	**29**	**85**	**119**	**12.23**	**16.21**	**31**	**61**	**4.85**	**9.94**

Bowhead Whales

Sighting rates.—Bowhead sighting rates were calculated for surveys conducted in 2006 and 2007 during seismic, post–seismic, and non–seismic periods, excluding periods of poor sightability (Figure 7.3). Where possible, these data were sub–divided into three areas relative to the center of seismic survey activity: east, central, and west, as described in the methods section.

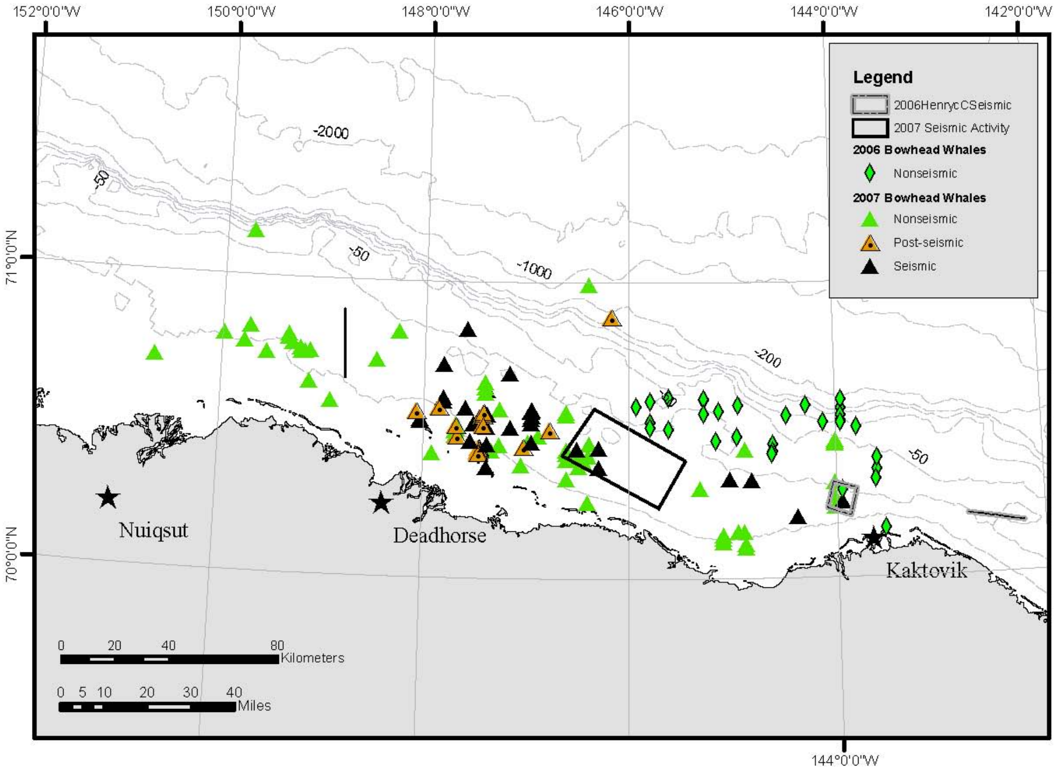


FIGURE 7.3. Bowhead sightings relative to the seismic prospects in the Alaskan Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Colors indicate seismic state at time of sighting.

Sighting rates in 2007.—Bowheads were seen on 69% of surveys in 2007 and group size ranged from one to 12, with an average of 1.4 individuals/sighting. In total, observers in 2007 made 85 useable sightings of 119 individual bowheads.

In general, bowhead sighting rates were higher than average sighting rates as previously reported (Figure 7.4; average from 1979-200 as calculated in Miller et al. 2002). When assessed by seismic state, sighting rates were highest in non–seismic periods (18.7 sightings/1000 km; 11.6 sightings/1000 mi; Table 7.2), and lowest during post–seismic periods (10.3 sightings/1000 km; 6.4 sightings/1000 mi). Within the three sub–areas, sighting rates were highest in the eastern area (16.9 sightings/1000 km; 10.5 sightings/1000 mi; Table 7.2) and lowest in the central area (8.2 sightings/1000 km; 5.1 sightings/1000 mi). In general, sighting rates within each of the sub–areas were highest during non–seismic periods. This pattern, however, did not hold true for the western area; here sighting rates were much higher during seismic and post–seismic periods than during non–seismic periods. The only significant difference in sighting rates by seismic state was observed in the central area ($P<0.01$; Table 7.3). The small size of these datasets and lack of detail at a day–to–day or seasonal scale makes statistical interpretation difficult, however, and easily influenced by stochasticity.

Bowheads were first sighted on 22 Aug and last sighted on 3 Oct. Daily bowhead sighting rates increased slightly from late Aug through mid–Sep, peaking on 18 Sep (19.8 sightings/1000 km; 31.9 sightings/1000 mi; Figure 7.4). This pattern was consistent with autumn migration of bowheads into Alaskan waters during late Aug through Oct (Wartzok et al. 1989; Moore and Reeves 1993; Miller et al. 1999, 2002; Mate et al. 2000; Treacy 2000), though observations of activity indicated that migration out of the area may have been later than normal (see *Activities in 2007*).

Sighting rates in 2006 and other studies.—In 2006, bowheads were seen on 89% of survey days with group sizes ranging from one to four and with an average of 1.5 individuals/group. All data in 2006 were non–seismic, so no responses to seismic activity could be assessed. Daily sighting rates fluctuated over the course of the 2006 study period, with peaks on 6 Sep (26.1 sightings/1000 km; 42 sightings/1000 mi) and 23 Sep (35.1 sightings/1000 km; 56.5 sightings/1000 mi) and lowest, with no sightings, on 24 Sep. Overall, sighting rates were higher than the average from previous studies (Figure 7.4).

Temporal patterns in sighting rates for 2006 and 2007 were similar to those observed in other studies, with peak sighting rates in early Sep. Reviewing data from 1979–2000, Miller et al. (2002) found high sighting rates in early Sep and early Oct with peak rates in late Sep (Figure 7.4) and much lower rates in Aug. Typical patterns in bowhead sighting rates over time (Table 7.4; Miller et al. 2002) show peaks followed by declines corresponding to pulses of whales passing though the area. The dramatic decline from 23 to 24 Sep in 2006 confirmed that whales were migrating through the study area at that time rather than lingering to feed.

TABLE 7.2. Bowhead sightings and sighting rates in the Beaufort Sea by seismic state, 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007.

				Seismic	Post-seismic	Non-seismic	Total
2006							
	All sightings						
		All areas	Sightings	--	--	46	46
			Individuals	--	--	66	66
			Sightings/1000 km	--	--	16.2	16.2
			Individuals/1000 km	--	--	23.3	23.3
	Useable sightings						
		All areas	Sightings	--	--	31	31
			Individuals	--	--	45	45
			Sightings/1000 km	--	--	10.9	10.9
			Individuals/1000 km	--	--	15.9	15.9
2007							
	All sightings						
		All areas	Sightings	31	18	73	122
			Individuals	35	37	90	162
			Sightings/1000 km	17.9	10.3	18.7	16.5
			Individuals/1000 km	20.2	21.2	23.1	22.0
	Useable sightings						
		Harrison Bay	Sightings	--	--	13	13
			Individuals	--	--	14	14
			Sightings/1000 km	--	--	8.7	8.7
			Individuals/1000 km	--	--	9.3	9.3
		West	Sightings	11	12	15	38
			Individuals	12	31	21	64
			Sightings/1000 km	17.9	18.1	9.6	13.4
			Individuals/1000 km	19.5	46.8	13.4	22.5
		Central	Sightings	5	2	21	28
			Individuals	7	2	23	32
			Sightings/1000 km	6.8	1.8	13.2	8.2
			Individuals/1000 km	9.5	1.8	14.4	9.4
		East	Sightings	3	--	16	19
			Individuals	3	--	20	23
			Sightings/1000 km	7.8	--	21.8	16.9
			Individuals/1000 km	7.8	--	27.2	20.5
		Total	Sightings	19	14	52	85
			Individuals	22	33	64	119
			Sightings/1000 km	10.9	8.0	13.3	11.5
			Individuals/1000 km	12.7	18.9	16.4	16.1

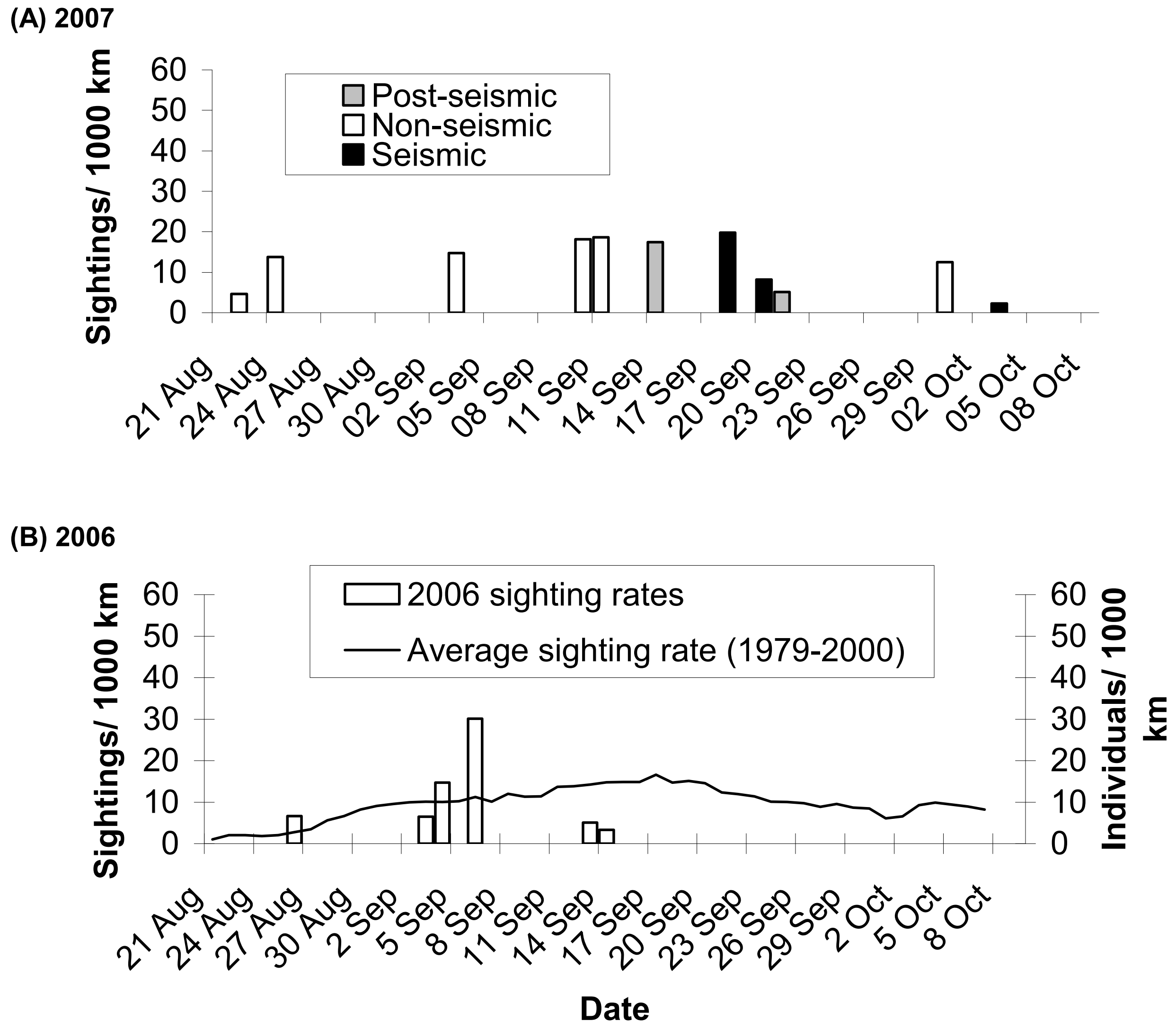


FIGURE 7.4. Daily sighting rates of bowheads in the central Beaufort Sea from 22 Aug through 8 Oct 2007 and from 26 Aug through 24 Sep 2006. Sighting rates are not shown for dates with survey effort <250 km. Plot of daily 10–day moving average of bowhead abundance (individuals/ 1000 km) in the eastern Alaskan Beaufort Sea, 21 Aug to 8 Oct 1979 2000 (adapted from Miller et al. 2002)

TABLE 7.3. Comparison of the numbers of observed vs. expected bowhead sightings relative to seismic state in Camden Bay for data collected from 22 Aug through 8 Oct 2007 as assessed by the Chi–Square Goodness–of–Fit test.

Area		Seismic	Post-seismic	Nonseismic	X^2	One-tailed *P*
All	Sightings (obs.)	19	14	52	3.037	0.22
	Sightings (exp.)	20.0	20.1	44.9		
	Effort (km)	1736.5	1746.5	3897.2		
East	Sightings (obs.)	3	--	16	2.938	0.09
	Sightings (exp.)	6.6	--	12.4		
	Effort (km)	387.1	--	735.5		
Central	Sightings (obs.)	5	2	21	10.297	<0.01
	Sightings (exp.)	6.0	8.9	13.1		
	Effort (km)	735.4	1083.5	1595.9		
West	Sightings (obs.)	11	12	15	3.741	0.15
	Sightings (exp.)	8.2	8.9	20.9		
	Effort (km)	614.0	663.1	1565.8		

TABLE 7.4. Peak bowhead sighting rates over time, from Aug to Oct, in the Alaskan Beaufort Sea, with respect to years and location of studies.

Year	Location	Period With Peak Sighting Rates (Aug - Oct)	Sighting rate (sightings/1000 km)	Author
1979-2000	Flaxman Is - Herschel Is	16-30 Sep	10.3	Miller et al. 2002
1996-1997	Harrison Bay - Flaxman Is	1-10 Sep	11.3	Miller et al. 1999
1998	Oliktok Pt - Flaxman Is	11-20 Sep	10.2	Miller et al. 1999
2006	Camden Bay	23 Sep	35.1	Thomas et al. 2006
2007	Nuiqsut - Kaktovik	18 Sep	19.8	Current study

***Abundance in 2007.*—**The numbers of bowheads present in Harrison and Camden bays in 2007 were estimated using DISTANCE software (Tables 7.5, 7.6). Separate estimates were made for Harrison Bay and Camden Bay due to differences in survey altitude and in the areas surveyed.

In total, 13 bowhead sightings, with an average group size of 1.1 individuals, were made in Harrison Bay from 22 Aug through 3 Sep (Table 7.5). Approximately 452 (bootstrapped mean based on data in Table 7.5, s.d.=237, 95% C.I.=109–916) bowhead whales were estimated to be in the study area during that period. Estimates of the number of bowheads present during each survey ranged from 109 (Survey 1) to 916 (Survey 3), but effort was marginal during Surveys 2 and 3 and these estimates should be treated cautiously.

A total of 72 bowhead sightings, with an average group size of 1.5 individuals, was made on surveys conducted in Camden Bay from 10 Sep through 8 Oct (Table 7.6). Estimates of the number of bowheads present during each survey varied from 284 (Survey 11) to 4826 (Survey 5; Table 7.6) for surveys with effort sufficient for estimates. A single weighted average of the number of whales present during this period was considered inappropriate because predominant activity changed during the survey period from feeding to traveling (as interpreted by the observed activities of whales, described below). Many of the whales sighted during Sep did not appear to be actively migrating and probably lingered in the area; whereas, whales observed during Oct appeared to be migrating and most likely moved through the survey area in less than one day. Thus separate weighted average densities were calculated for migratory and non–migratory periods. From 10 through 30 Sep the bootstrapped average bowhead abundance in Camden Bay was 2723 individuals (bootstrapped mean based on data from Table 7.6, s.d.=497, 95% C.I.=1689–3617); from 2 through 8 Oct, after migration was thought to have commenced, the bootstrapped average abundance estimate was 306 individuals (bootstrapped mean based on data from Table 7.6, s.d.=130, 95% C.I.=0–557).

TABLE 7.5. Estimated numbers of bowhead whales in Harrison Bay, 22 and 24 Aug and 3 Sep 2007. Estimates obtained using DISTANCE software for each individual survey. Numbers in parentheses should be interpreted with caution due to low effort (<500 km or 311 mi). Estimates include allowance for f(0) (as calculated by DISTANCE) and g(0) (value of 0.144 from Thomas et al. 2002.).

Survey No.	Date in 2007	Effort (km)	Sightings	Density (No./1000 km^2)	Est. No. Whales	95% C.I.	
1	22 Aug	869	4	11.5	109	32	365
2	24 Aug	290	4	(68.9)	(653)	163	2617
3	3 Sep	339	5	(58.8)	(916)	325	2582

TABLE 7.6. Estimated numbers of bowhead whales in Camden Bay from 10 Sep through 8 Oct 2007. Estimates were obtained using DISTANCE software for each individual survey. Numbers in parentheses represent estimates that should be interpreted with caution due to low effort (<500 km or 311 mi). No estimates were calculated (NC) when effort was less than 250 km (155 mi). Estimates include allowance for *f*(0) (as calculated by DISTANCE) and *g*(0) (value of 0.144 from Thomas et al. 2002.).

Survey No.	Date in 2007	Effort (km)	Sightings	Density (No./1000 km^2)	Est. No. Whales	95% C.I.	
4	10 Sep 11 Sep	1809	33	127.2	3047	1465	6338
5	11 Sep 14 Sep	605	11	179.0	4826	1513	15397
6	18 Sep 19 Sep	715	14	132.5	3176	1651	6109
7	20 Sep	488	4	(13.9)	(332)	(63)	(1755)
8	21 Sep	1178	6	86.2	2065	323	13214
9	26 Sep	51		NC	NC	--	--
10	30 Sep	241	3	NC	NC	--	--
11	2 Oct 3 Oct	571	1	11.8	284	59	1364
12	3 Oct	73		NC	NC	--	--
13	7 Oct 8 Oct	151		NC	NC	--	--

Abundance in 2006.—A total of 33 bowhead whale sightings, with an average group size of 1.1 individuals, was seen during 2006. Abundances in 2006 were also calculated using DISTANCE software. Estimates suggested that approximately 529 (bootstrapped mean based on data in Table 7.7; s.d.=242, 95%C.I.=148–1049; Table 7.7) bowhead whales were present in the study area during surveys conducted in 2006. Estimates from individual surveys ranged from 0 (Surveys 2 and 7) to 1755 (Survey 4). The aircraft used for surveys in 2006 did not have wing–tip tanks and was not able to complete more than approximately 300 km of survey effort before refueling; therefore, all 2006 surveys consisted of less than 500 km (311 mi) of effort. As such, estimates should be treated cautiously.

TABLE 7.7. Estimated numbers of bowhead whales in the central Beaufort Sea from 26 Aug through 24 Sep 2006. Estimates were obtained using DISTANCE software for each individual survey. Numbers in parentheses represent estimates that should be interpreted with caution due to low effort (<500 km or <311 mi). No estimates were calculated (NC) when effort was less than 250 km (155 mi). Estimates include allowance for *f*(0) (as calculated by DISTANCE) and *g*(0) (value of 0.144 from Thomas et al. 2002.).

Survey No.	Date in 2006	Effort (km)	Sightings	Density (No./1000 km^2)	Est. No. Whales	95% C.I.	
1	26 Aug	449	(3)	(43.0)	(243)	(58)	(1024)
2	3 Sep	463	(3)	(0.0)	(0)	(0)	(0)
3	4 Sep	477	(7)	(76.5)	(433)	(88)	(2137)
4	6 Sep	498	(13)	(310.2)	(1755)	(553)	(5567)
5	12 Sep	83	(1)	NC	NC	NC	NC
6	13 Sep	397	(2)	(97.2)	(550)	(73)	(4148)
7	14 Sep	303	(1)	(0.0)	(0)	(0)	(0)
8	23 Sep	29	(1)	NC	NC	NC	NC
9	24 Sep	132	(0)	NC	NC	NC	NC

Distance from shore and depth in 2007.— Survey effort was greatest in areas <20 km (12 mi) offshore in both Harrison and Camden bays (Figure 7.5). When assessed by sub–area, effort in Camden Bay was greatest in the central area, while in Harrison Bay it was greatest in the west. Trends in sighting rates by distance from shore were assessed separately for Camden and Harrison bays because all data from Harrison Bay were non–seismic and, if pooled, could mask trends within Camden Bay.

Sighting rates in Camden Bay were highest (60.6 sightings/1000 km; 37.6 sightings/1000 mi) 15–20 km (9–12 mi) from shore (Figure 7.6). Within sub–areas, peak sighting rates varied from 10–15 km (6–9 mi) offshore in the east, to 20–25 km (12–15 mi) in the central area. Sighting rates in Harrison Bay were highest 20–25 km (12–15 mi) offshore (Figure 7.6), and this trend was also true for the western and eastern areas. Peak sighting rates in the eastern area of Harrison Bay were slightly farther (30–35 km; 19–22 mi) offshore (Appendix Table D.2).

Offshore distribution of sighting rates was also assessed by seismic state. No differences in offshore distribution by seismic state were significant (Figure 7.6 and Table 7.8). Peak sighting rates in Camden Bay varied less than 20 km (12 mi) by seismic state, with peak rates farthest offshore (20–25 km; 12–15 mi) during seismic periods and closest to shore (5–10 km; 3–6 mi) during non–seismic periods. Similar patterns were observed in the central and eastern areas, with values in the central area slightly farther offshore (10 km or less; 6 mi or less) than in the east. In contrast, peak sighting rates in the west were farthest offshore during post–seismic periods (15–20 km; 9–12 mi) and nearest to shore during non–seismic periods (5–10km; 3–6 mi). Sighting rates for all distance from shore bins in each area and seismic state are presented in Appendix Table D.1 and D.2).

Additionally, most sightings were made in waters less than 50 m (55 yds) deep in both Harrison and Camden bays (Figure 7.7). The majority of seismic sightings appeared to be of whales in waters from 25–50 m (82–164 ft) deep, while non–seismic sightings tended to vary more.

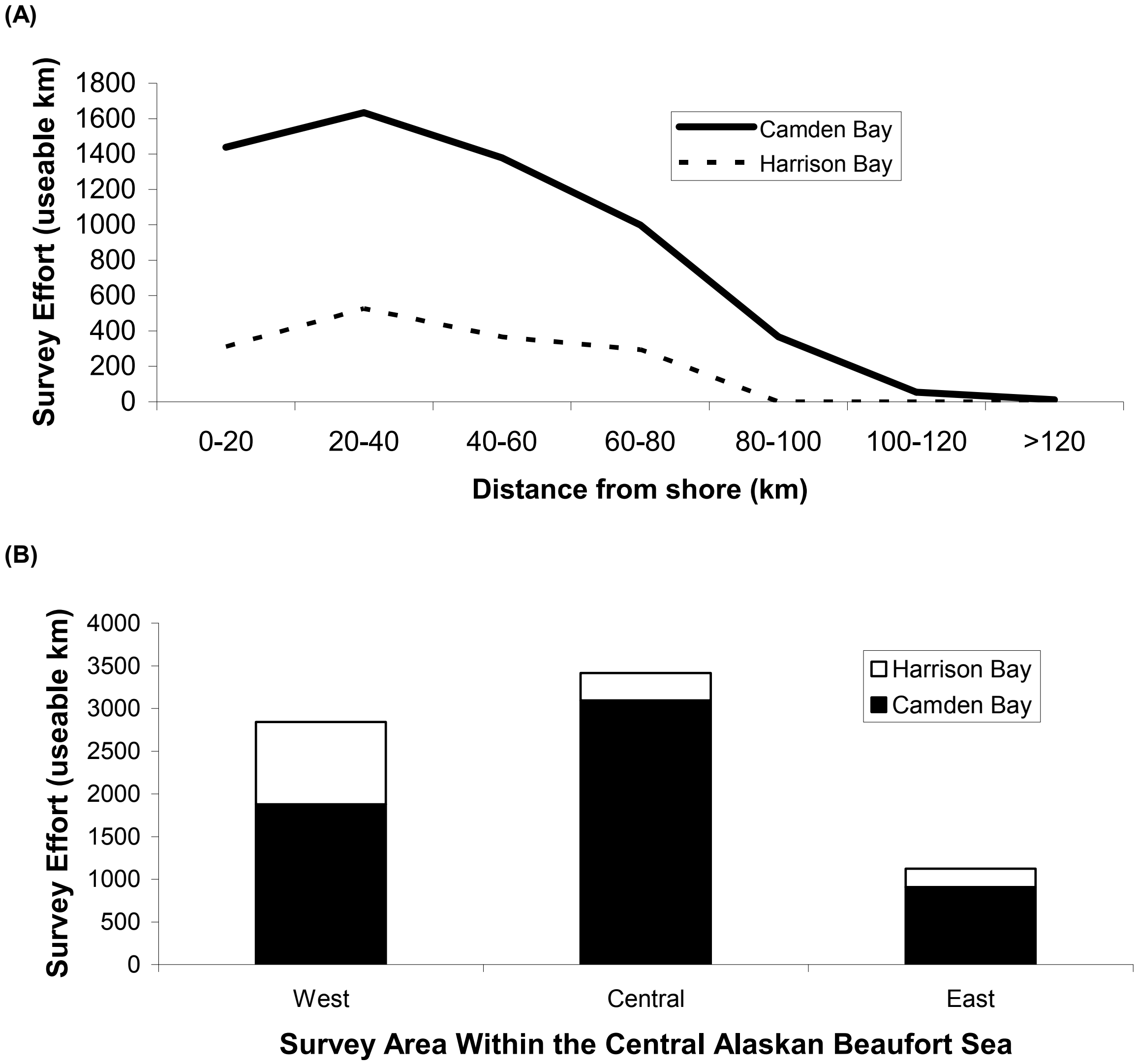


FIGURE 7.5. Survey effort within the Beaufort Sea. (A) Total survey effort (km) in Harrison and Camden bays from 22 Aug through 8 Oct 2007. (B) Total survey effort (km) within the west, central and east survey areas in Harrison and Camden bays from 22 Aug through 8 Oct 2007.

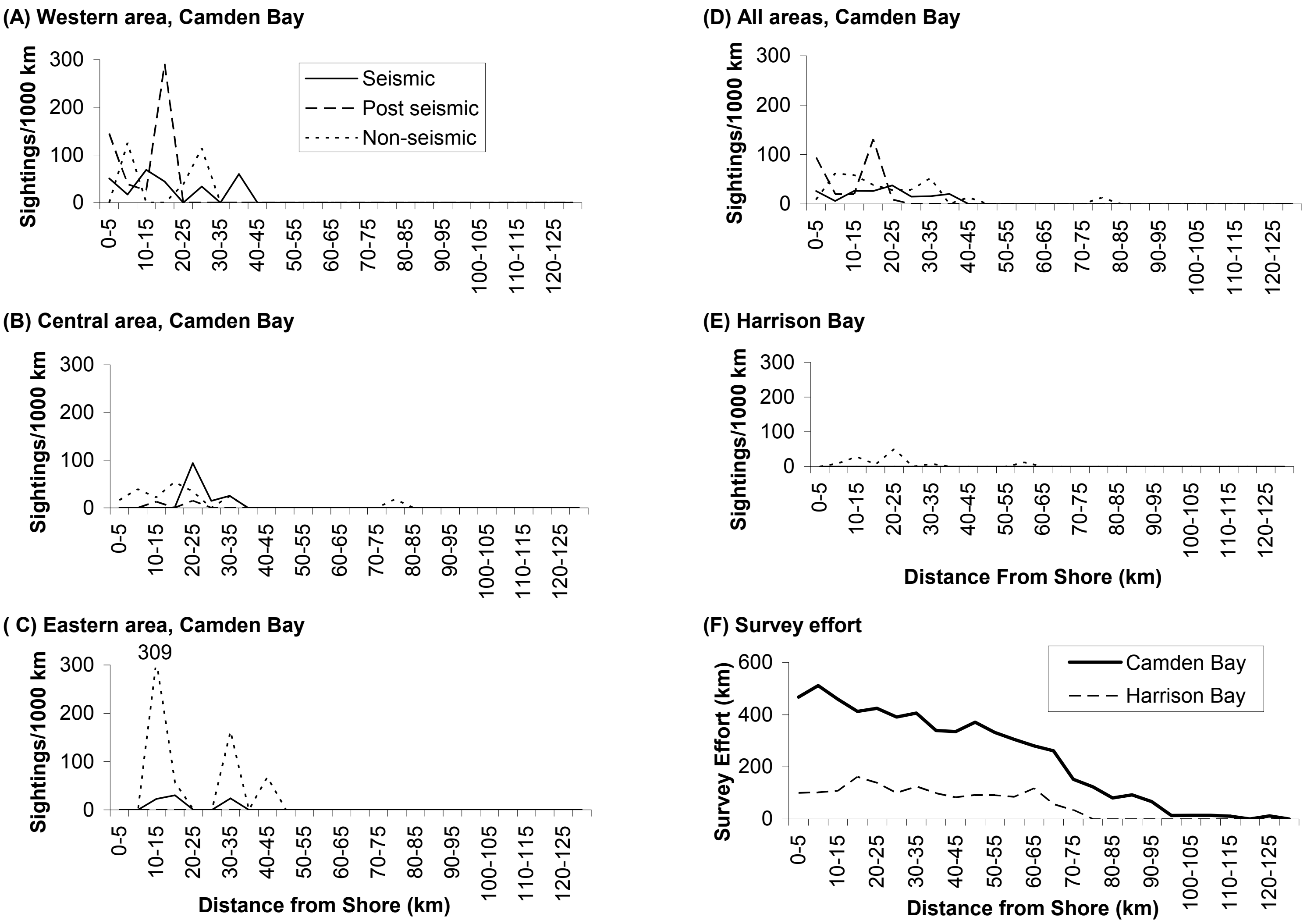


FIGURE 7.6. Bowhead sighting rates from 22 Aug through 8 Oct 2007 within sub–areas of Camden Bay and within Harrison Bay, (A) western area, (B) central area, (C) eastern area, (D) all areas, (E) Harrison Bay, and (F) survey effort.

TABLE 7.8. Results of statistical analysis (Kolmogorov–Smirnov test) comparing offshore distributions of bowhead sighting rates, by 5 km distance from shore bins, during seismic and non–seismic periods within Camden Bay from 22 Aug to 8 Oct 2007. Effort and sightings refers to the number of distance from shore bins in which effort or sightings took place. No comparison was made using data from Harrison Bay as all data in that area were non–seismic.

Area	Test of	Seismic		Non-seismic		Two-tailed *P*	
		Effort	Sightings	Effort	Sightings	D_{max}	Bootstrapped *P*
All	Sightings/1000 km by distance from shore	24	8	21	9	0.244	0.517
East	Sightings/1000 km by distance from shore	17	3	19	4	0.211	0.821
Central	Sightings/1000 km by distance from shore	24	3	20	7	0.267	0.420
West	Sightings/1000 km by distance from shore	17	6	19	3	0.195	0.884

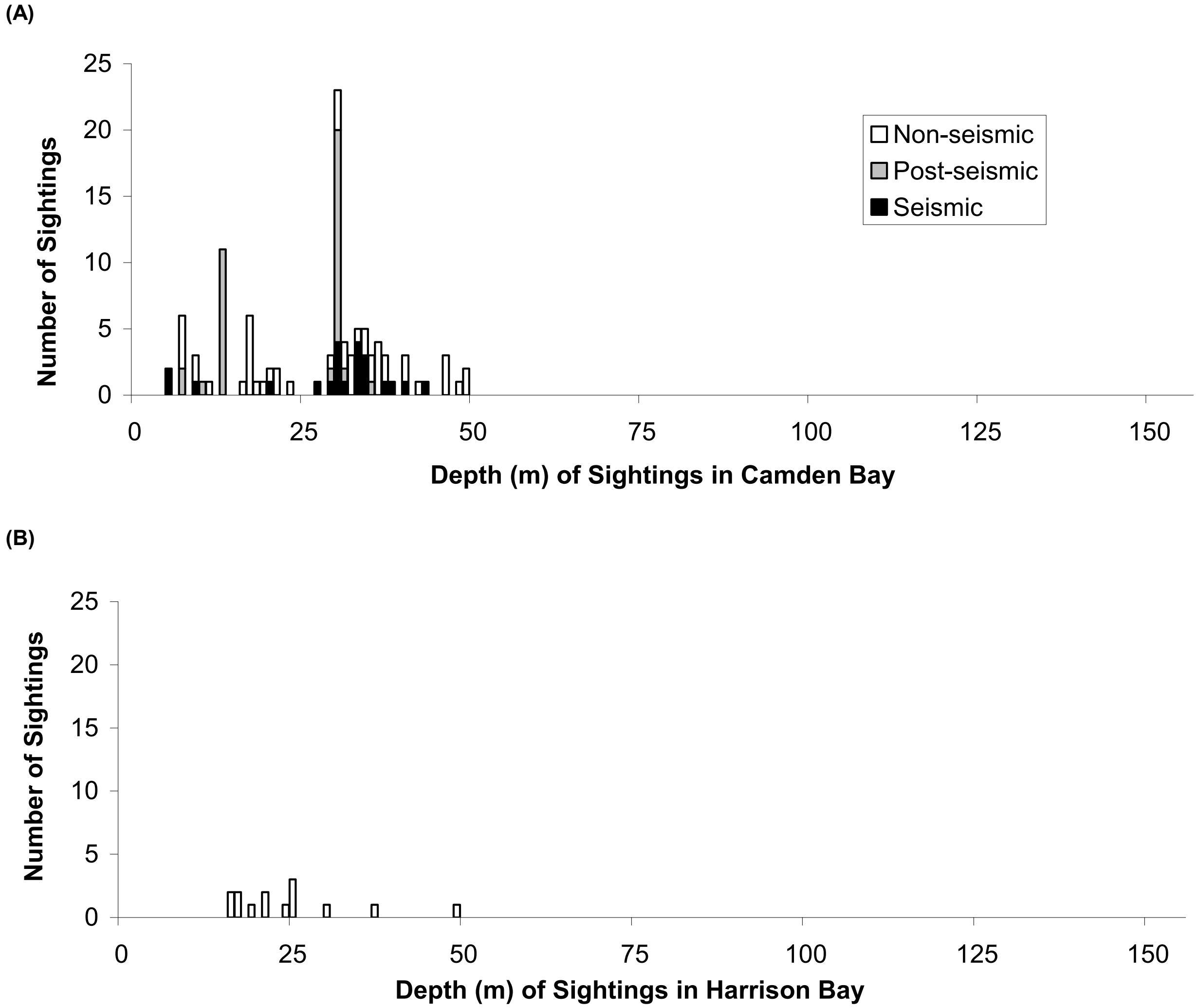


FIGURE 7.7. Number of bowhead sightings in (A) Camden and (B) Harrison bays in the central Beaufort Sea by depth (m) with seismic state indicated by color. Data collected from 22 Aug through 8 Oct 2007. One additional non–seismic sighting was made in Camden Bay, at a depth of 580 m, but was excluded as an outlier.

Distance from shore and depth in 2006 and other studies.—In 2006, sighting rates peaked at 40–45 km (25–28 mi) offshore (Figure 7.8 and Appendix Table D.3). Effort peaked in the first 10 km (6 mi) from shore. In addition, the majority of sightings were in waters <50m (164 ft) deep (Figure 7.9).

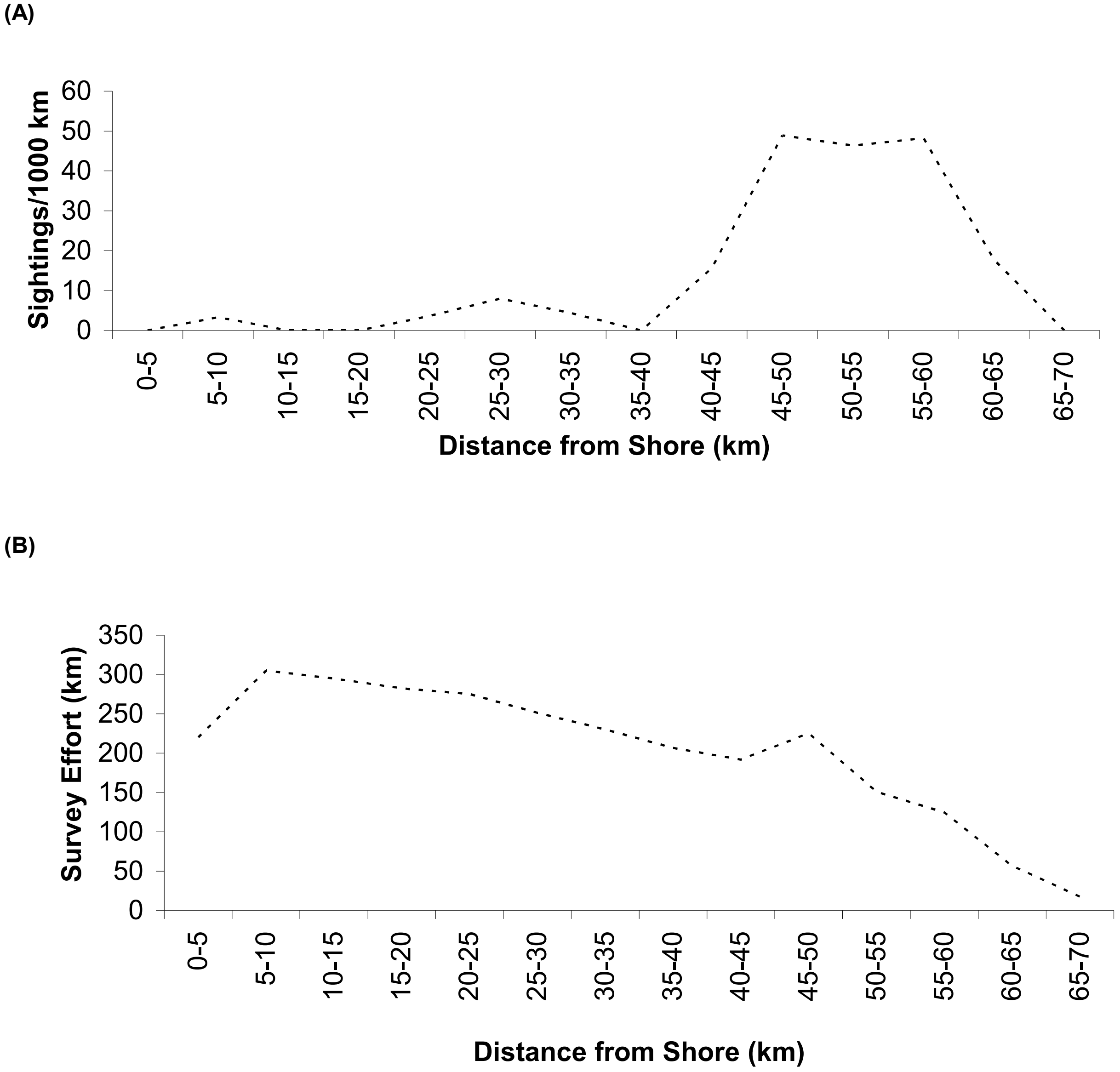


FIGURE 7.8. (A) Bowhead sighting rates by distance from shore from 26 Aug through 24 Sep 2006 in the central Beaufort Sea. (B) Survey effort for the same period.

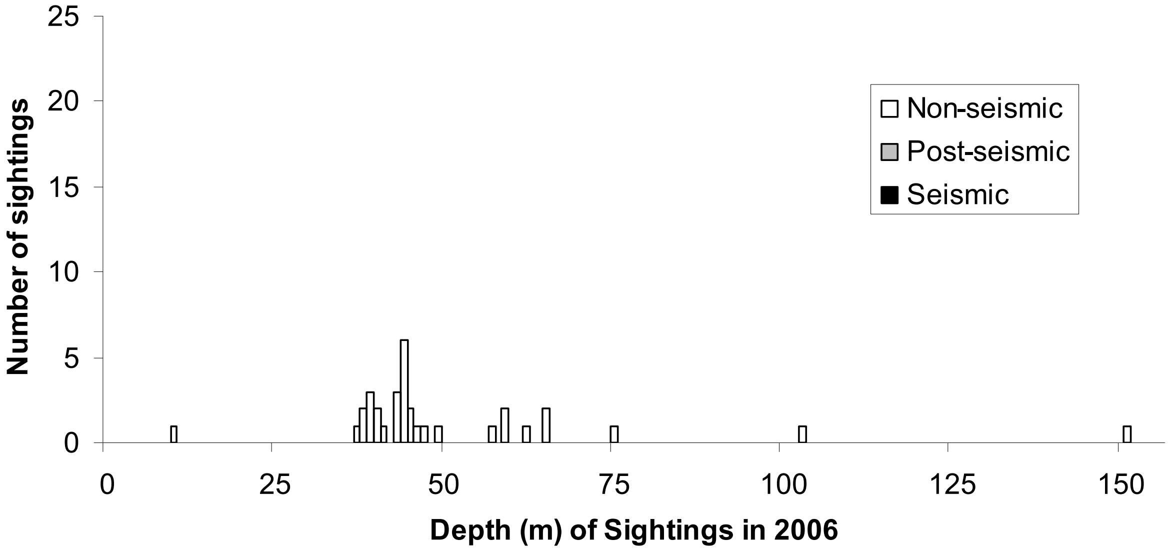


FIGURE 7.9. Number of bowhead sightings in the central Beaufort Sea by depth (m) with seismic state indicated by color. Data collected from 26 Aug through 24 Sep 2006.

Patterns in offshore bowhead distribution have been studied in a series of MMS reports since 1982 (Treacy 2002). In these studies, the Beaufort Sea was subdivided into two areas, western (from Barrow to Deadhorse) and eastern (from Deadhorse to Herschel Island). Data collected during these studies (Figure 7.10) indicated that within both the eastern and western areas, offshore bowhead distribution, though highly variable among years, was highest approximately 30–90 km (19–56 mi) from shore. Patterns in water depth at sighting locations were also recorded in these studies (Figure 7.11) and trends in these data indicate that, in general, the majority of bowhead sightings were made in waters less than 250 m (820 ft) deep.

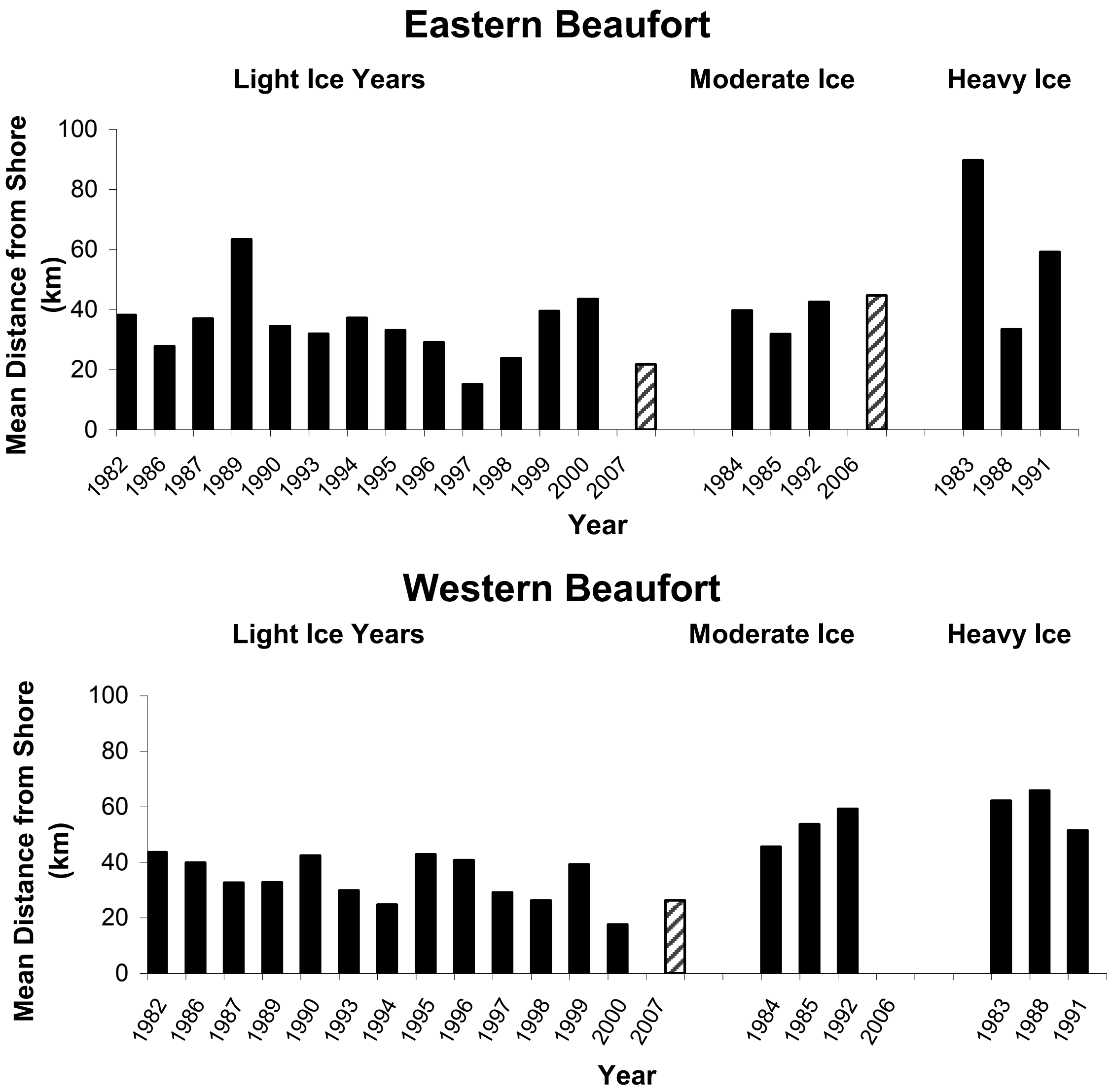


FIGURE 7.10. Mean distance (km) from shore of bowhead whale sightings during annual fall aerial surveys conducted by Minerals Management Service in the Alaskan Beaufort Sea from 1982 through 2000 (Treacy 2002). Striped columns represent data collected in this study.

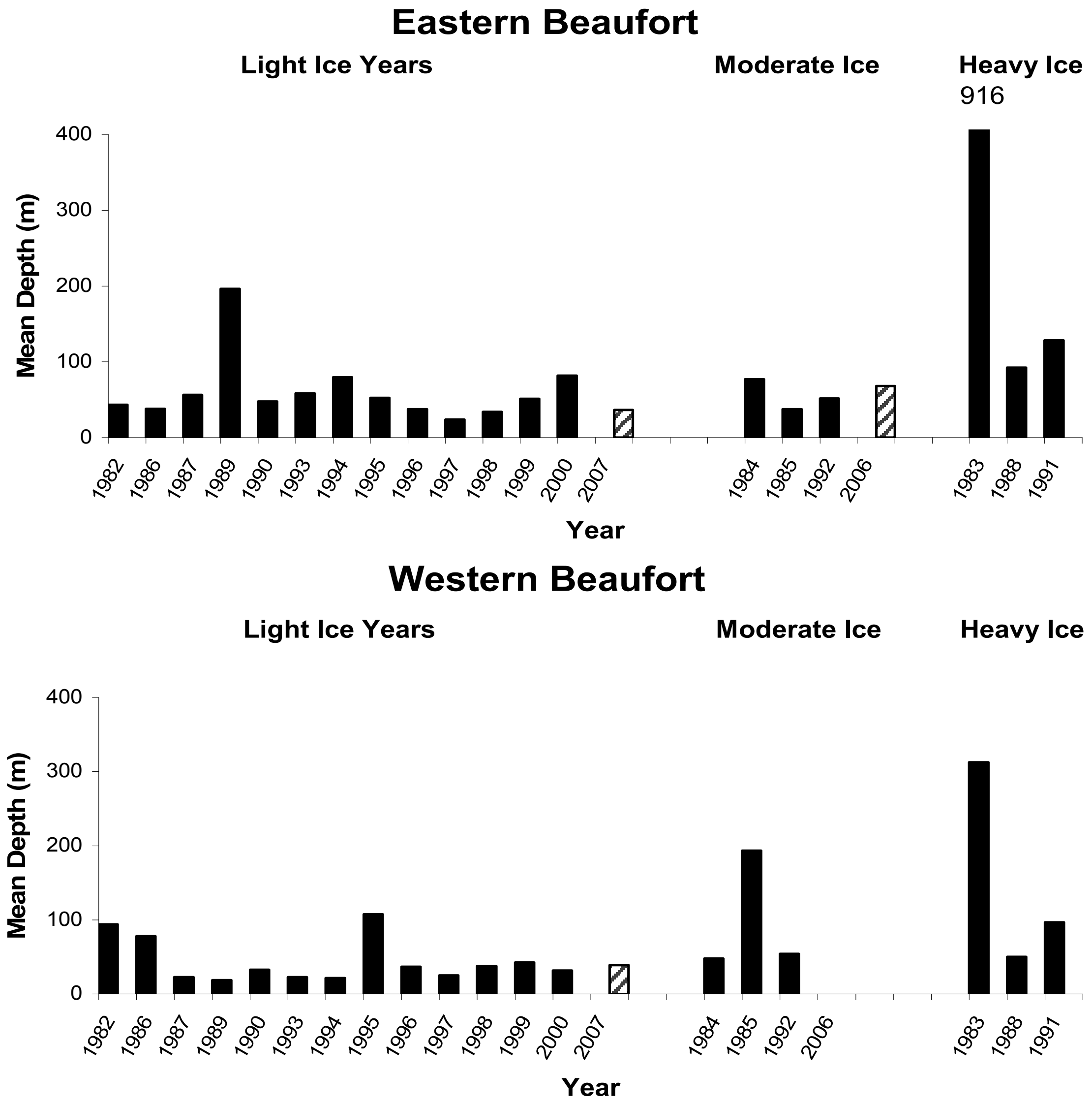


FIGURE 7.11. Mean depth (m) of bowhead whale sightings during annual fall aerial surveys conducted by Minerals Management Service in the Alaskan Beaufort Sea from 1982 through 2000 (Treacy 2002). Striped columns represent data collected during this study.

Additional studies (Table 7.9) assessing primarily the same MMS data from 1982–2000 have shown that the offshore distribution of bowheads, by depth contour, follows a distinct pattern with regard to ice cover. Moore et al. (2000) found that in heavy ice years, bowhead sighting rates were highest in continental slope waters (>200 m; >656 ft), while in moderate or light ice years whales were more frequently sighted in shallow, inner shelf waters (<50 m; <164 ft). Treacy et al. (2006) found similar patterns in bowhead distribution and hypothesized that this was due to a restriction of habitat caused by the development of a zone of ridging between landfast ice and shoreward moving annual pack ice during heavy ice years. A review paper, assessing offshore bowhead distribution, without regard to ice cover found that, over a 21 year period, peak sighting rates of bowhead whales tended to be in waters 20–200 m (66–656 ft) deep (Miller et al. 2002).

TABLE 7.9. Relationships between location, ice cover and peak sighting rates of bowhead whales by depth categories in the Alaskan Beaufort Sea.

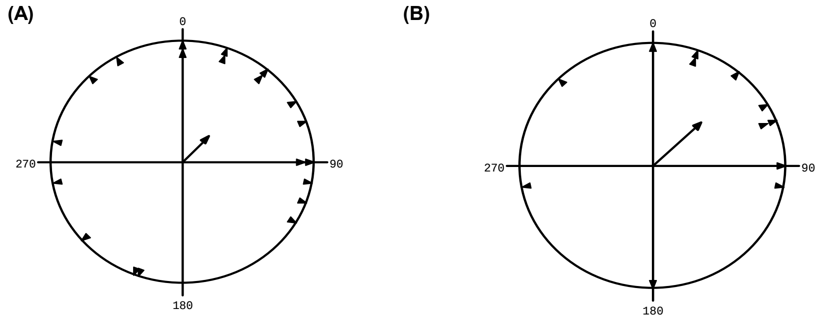
Year	**Location**	**Ice Cover**	**Depth Bin (m) with Peak Sighting Rate (Aug - Oct)**	**Author**
1979-2000	Flaxman Is - Herschel Is	Variable	20-200	Miller et al. 2002
1982-1991	Bering Strait - Canadian Border	Heavy	>200	Moore et al. 2000
		Moderate-light	<50	
2006	Camden Bay	Moderate	<50	Thomas et al. 2006
2007	Nuiqsut - Kaktovik	Light	<50	Current study

Distribution around seismic operations in 2007.—Data were also examined with respect to the distance of sightings from the center of seismic activity in 2007. In total, 31 bowhead sightings (35 individuals) were made during seismic activity, all in Camden Bay; 19 of these sightings (22 individuals) were under useable conditions (Appendix Table D.4). Fourteen and 39 useable sightings were recorded during post–seismic and non–seismic periods, respectively. In general, bowhead sightings tended to be slightly farther from the center of the Sivulliq prospect during periods of active seismic work (56 km or 35 mi) and during post–seismic periods (53 km or 33 mi) than during non–seismic periods (51 km or 31 mi), though this trend was not significant (Table 7.10).

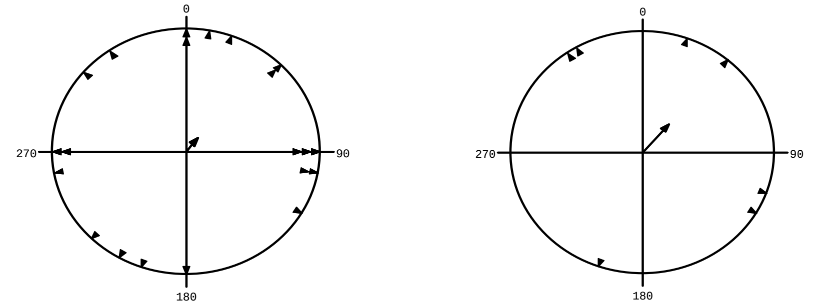
TABLE 7.10. Minimum, maximum and mean distance (km) of useable bowhead whale sightings in the central Beaufort Sea from center of the Sivulliq prospect during seismic, non–seismic, and post–seismic periods from 10 Sep through 8 Oct 2007. Statistical differences evaluated using the Mann–Whitney U test.

Seismic State	Number of Sightings				Two-tailed *P*
	n	Min.	Max.	Mean	
Seismic	19	10.5	81.2	56.0	0.481
Post-seismic	14	29.6	77.3	53.1	
Non-seismic	39	12.6	79.2	50.6	

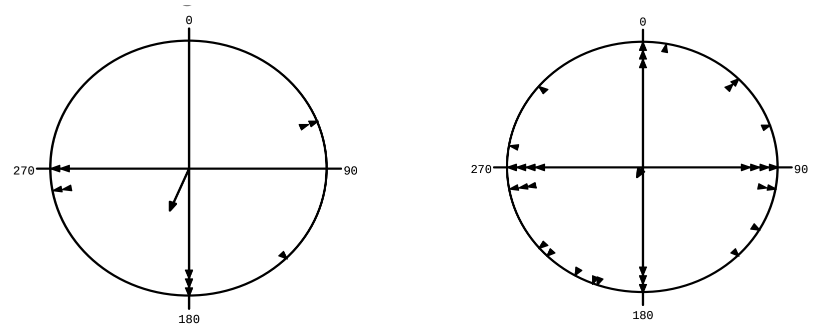
Headings in 2007.—Headings were recorded for 51 useable bowhead sightings in 2007. When plotted, these headings showed a uniform distribution, with no strong patterns evident (Figure 7.12). Vector mean heading for overall sightings was 53°T, with a fairly large circular standard deviation of 121°T (*P*=0.56; Appendix Table D.5).



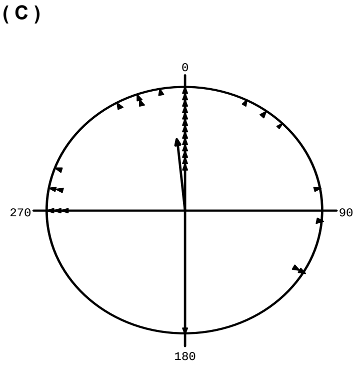
West, all periods (n=20) **All seismic (n=12)**



Central, all periods (n=21) **All post-seismic (n=7)**



East, all periods (n=10) **All nonseismic (n=32)**



2006, all periods and areas (n=33)

FIGURE 7.12. Bowhead headings by (A) area and (B) seismic state within the central Alaska Beaufort Sea from 22 Aug through 8 Oct 2007. (C) All bowhead headings observed from 26 Aug through 24 Sep 2006.

The numbers of sightings were insufficient to provide meaningful conclusions on whale headings relative to seismic state and geographic subdivision of the study area. When all areas were combined during seismic and post–seismic periods, bowhead vector mean headings were significantly different from random. Unexpectedly, the mean heading was northeast (46°T, *P*=0.04 and 41°T, *P*=0.05; Appendix Table D.5), rather than west to northwest, as would be expected for migrating whales. In contrast, bowheads sighted during non–seismic periods had random headings, with a non–significant vector mean heading to the south–southwest (207°T, circular s.d. = 125°T, *P*=0.77).

When assessed by area, the number of sightings was too small to make any conclusions about headings relative to seismic state, but during all seismic states combined, bowheads in western and central areas had random headings with a non–significant vector mean heading to the northeast (42°T, *P*=0.19 and 39°T, *P*=0.67) and bowheads sighted in the eastern area had random headings with a non–significant vector mean heading to the south–southwest (203°T, *P*=0.28).

***Headings in 2006 and other studies.*—**Headings were recorded for 31 useable bowhead sightings in 2006. These headings showed a strong pattern of north and slightly westward movement that might be expected for migrating whales (Figure 7.12). Vector mean for overall sightings was calculated to be 354°T, with a circular standard deviation of 60°T (*P*<0.01; Appendix Table D.5). Patterns in heading suggesting migration have been observed over similar time spans in several other studies (Table 7.11). Miller et al. (1999) reported that the vector mean of observed bowhead headings from 1996–1998 was 297°T (circular s.d.= 59°T). As part of a report assessing bowhead distribution and abundance in the central Beaufort Sea during late summer and autumn, Miller et al. (2002) assessed bowhead headings. In that report, data from 1979–2000 were assessed by half–month periods from Aug through Oct. Headings for all these periods were significantly different from uniform, with vector means ranging from 267–326°T. The exception was the period of 16–31 Aug when headings were not significantly different from uniform.

TABLE 7.11. Results of studies on bowhead headings in the Alaskan Beaufort Sea with respect to year, location and ice cover.

Year	Location	Ice Cover	Majority of Headings Migratory (Aug - Oct)	Author
1979-2000	Flaxman Is - Herschel Is	Variable	Yes	Miller et al. 2002
1996-1998	Harrison Bay - Flaxman Is	Variable	Yes	Miller et al. 1999
1998	Oliktok Pt - Flaxman Is	Light	Yes	Miller et al. 1999
2006	Camden Bay	Moderate	Yes	Thomas et al. 2006
2007	Nuiqsut - Kaktovik	Light	No	Current study

***Activities in 2007.*—**Data on bowhead activities were recorded for 45 sightings. Feeding (presumed through observations including open mouths, random headings, and quick dives) was the most commonly recorded activity (43%; Figure 7.13) with traveling (23%) and resting (11%) also frequently observed.

Activities during non–seismic periods were similar to overall trends, with presumed feeding accounting for 39% of recorded activities and traveling accounting for 25%. During post–seismic periods, presumed feeding and traveling were recorded with equal frequency, accounting for 33% of sightings. No bowheads sighted during seismic periods were recorded as traveling; the majority (75%) of recorded activity during seismic periods was presumed feeding (Fig. 7.14). When assessed by area, activities were similar, with presumed feeding being the predominant activity in all three areas, regardless of seismic state.

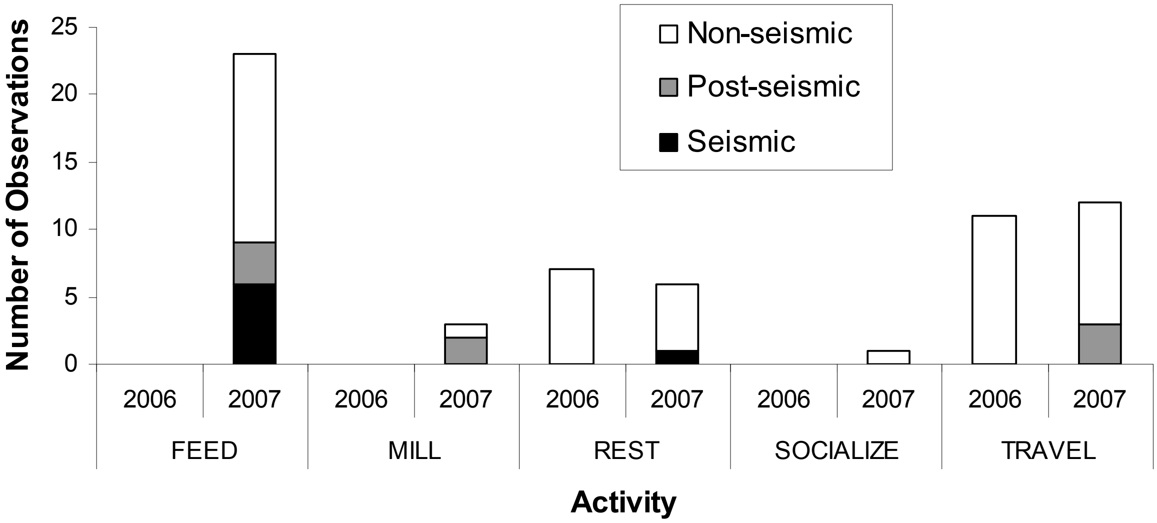


FIGURE 7.13. Observed activities of bowhead whales from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007 in the central Beaufort Sea. Seismic state at time of sighting indicated by color.

Activities in 2006 and other studies.—In 2006, data on bowhead activities were recorded for 18 sightings. Traveling was the most commonly recorded activity (61%) with resting (39%) the only other observed activity. Trends in bowhead activities within specific locations have been shown to vary greatly from study to study (Table 7.12). Studies by Miller et al. (1998 and 1999) found traveling to be the most commonly observed activity, accounting for 82% of observations in 1998 and 78% over the period of 1996–1998 from Harrison Bay to Flaxman Island. However, Würsig et al. (2002) found feeding to be the predominant activity (47% of observations) in four out of five years assessed (1985, 1986, 1998, 1999, but not 2000) to the east of the area studied by Miller et al. (1999).

TABLE 7.12. Most prevalent bowhead whale activity observed with respect to location and year during aerial survey studies in the Alaskan Beaufort Sea.

Year	Location	Most Prevalent Activity (Aug- Oct)	Author
1979-1984	Camden Bay	Non-feeding	Ljungblad 1986
1979-1984	Prudhoe Bay	Non-feeding	Ljungblad 1986
1979	Harrison Bay - Mackenzie Bay	Diving	Moore and Clarke 1986
1980-1984	Harrison Bay - Mackenzie Bay	Swimming	Moore and Clarke 1986
1985-1986	Harrison Bay - Mackenzie Bay	Feeding	Moore and Clarke 1986
1985	Flaxman Is - Herschel Is	Feeding	Wursig et al. 2002
1986	Flaxman Is - Herschel Is	Feeding	Wursig et al. 2002
1996-1997	Harrison Bay - Flaxman Is	Traveling	Miller et al. 1998
1998	Oliktok Pt - Flaxman Is	Traveling	Miller et al. 1999
1998	Flaxman Is - Herschel Is	Feeding	Wursig et al. 2002
1999	Flaxman Is - Herschel Is	Feeding	Wursig et al. 2002
2000	Flaxman Is - Herschel Is	Traveling	Wursig et al. 2002
2006	Camden Bay	Traveling	Thomas et al. 2006
2007	Nuiqsut - Kaktovik	Feeding	Current study

Speed in 2007.—The majority of recorded bowhead speeds (65%) in 2007 were considered slow (Figure 7.14). Moderate was the next most commonly recorded speed, comprising 20% of sightings. These patterns were similar for all seismic states and in all areas. Only one bowhead was considered to be moving fast; it was sighted east of seismic activity. Resting bowheads, with no speed, accounted for 12% of sightings.

Speed in 2006 and other studies.—In 2006, speed was recorded for six bowhead sightings. Five of these sightings were classified as moving slowly; one was classified as moderate. This is in contrast with work in other studies (Table 7.13). Miller et al. (1999) found that most observed whales were traveling at a moderate speed, regardless of seismic state (75.3% during seismic and 64.8% during non–seismic) in surveys conducted during 1998. Similarly, when pooled with data from 1996 and 1997, trends indicated an overall moderate speed with no differences related to seismic state (Miller 1999).

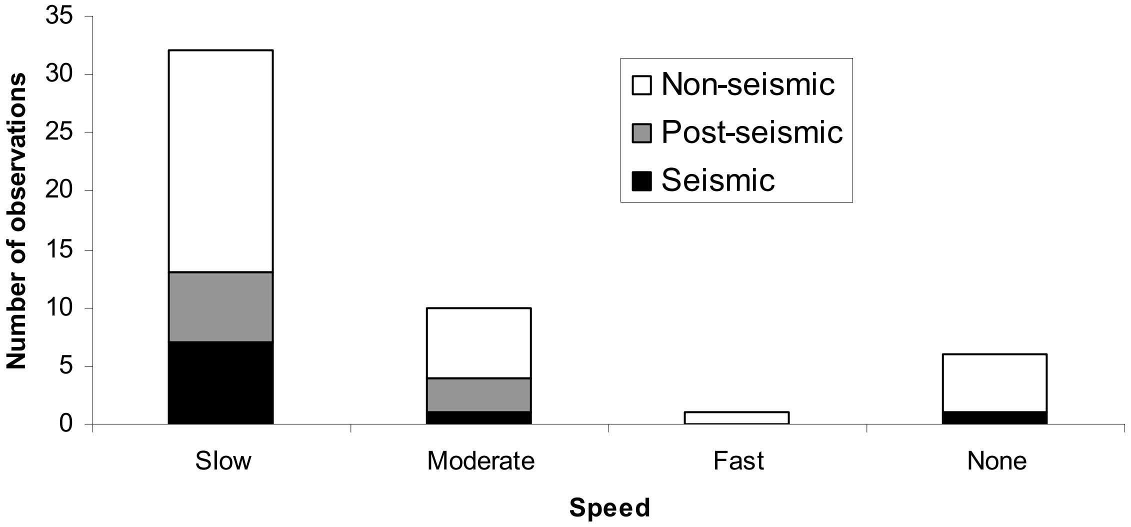


FIGURE 7.14. Observed speeds of bowhead whales in the central Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Seismic state at time of sighting indicated by color.

TABLE 7.13. Observed speeds of bowhead whales in the Alaskan Beaufort with respect to year, location and ice cover.

Year	Location	Ice Cover	Majority of Observed Speeds (Aug - Oct)	Author
1996-1998	Harrison Bay - Flaxman Is	Variable	Moderate	Miller et al. 1999
1998	Oliktok Pt - Flaxman Is	Light	Moderate	Miller et al. 1999
2006	Camden Bay	Moderate	Slow	Thomas et al. 2006
2007	Nuiqsut - Kaktovik	Light	Slow	Current study

Mitigation Measures Implemented

In 2007, the IHA required two surveys to be flown per week until 31 Aug and then daily surveys (weather permitting) from 1 Sep until three days following the end of seismic work. Only one cow/calf pair was seen during aerial surveys associated with seismic monitoring in Harrison and Camden bays during 2007. Mitigation measures (shut–down of operations) were required if four or more cow/calf pairs were sighted within the established 120 dB re 1 ɥPa (rms) radius during a survey and thus no mitigation measures were implemented due to observations of cow/calf pairs within the 120 dB radius in 2007.

Estimated Number of Bowheads Present and Potentially Affected

Two received level criteria have been specified by NMFS as relevant in estimating cetacean “take by harassment”:

- 180 dB re 1µPa (rms), above which there is concern about possible temporary effects on hearing;
- 160 dB re 1µPa (rms), above which avoidance and other behavioral reactions are may occur.

Using density estimates during non–seismic periods calculated with DISTANCE software and total ensonified area calculated with ArcView, the numbers of bowhead exposures to received sound levels >180 and 160 dB rms were estimated for each of the received level criteria (Table 7.14).

TABLE 7.14. Estimated number of individual bowhead whales exposed to received levels ≥180 and 160 dB (rms) during seismic survey activities by SOI in the central Beaufort Sea and average number of exposures per individual from 22 Aug through 8 Oct 2007.

Exposure level in dB re 1 uPa (rms)	Individuals Exposed	Exposures per individual	Requested take
≥180dB	40	6.68	220
≥160dB	192	18.88	1518

The exposure estimates in Table 7.14 were made based on density values calculated from non–seismic periods and hence do not reflect any avoidance behavior. These numbers are likely overestimates of the number of individuals exposed to the 160 and 180 dB re 1ɥPa (rms) levels, as it is possible some bowheads avoided seismic operations, as observed in previous studies (Richardson et al. 1995; Miller et al. 1999).

Beluga Whales

Sighting rates in 2007.—A total of 31 useable beluga sightings (61 individuals) was recorded during 2007 (Figure 7.15). Sightings were made on two days, 22 Aug and 11 Sep, both during non–seismic periods. Sighting rates for these days were 1.2 sightings/1000 km (1.9 sightings/1000 mi) and 27.9 sightings/1000 km (45.0 sightings/1000 mi), respectively (Figure 7.16).

Sighting rates in 2006.— In 2006, belugas were sighted on four days with sighting rates that ranged from 2.2 sightings/1000km (3.6 sightings/1000mi) on 26 Aug to 28.1 sightings/1000km (45.3 sightings/1000mi) on 6 Sep. In both years, sighting rates were generally highest during early Sep (Figure 7.16).

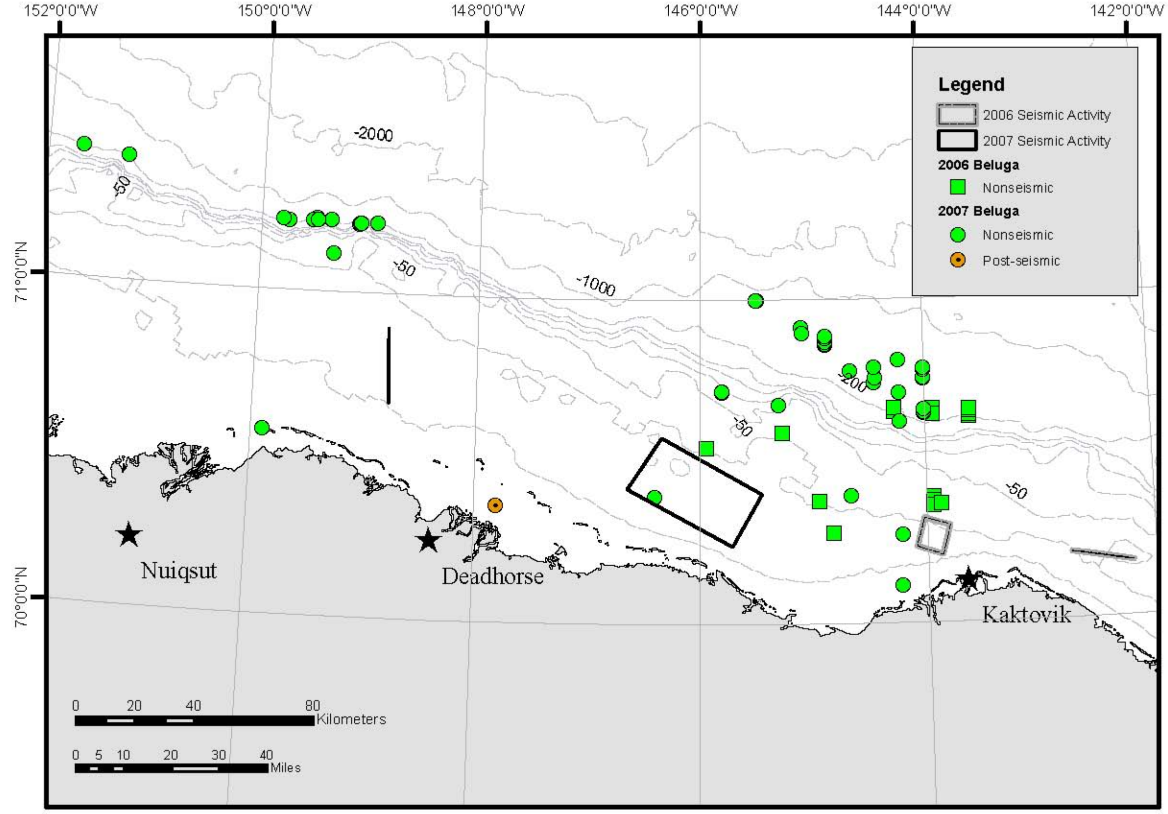


FIGURE 7.15. Beluga sightings relative to the seismic prospects explored in the Beaufort Sea from 26 Aug through 24 Sep and 22 Aug through 8 Oct 2007. Seismic state at the time of sighting is indicated by color.

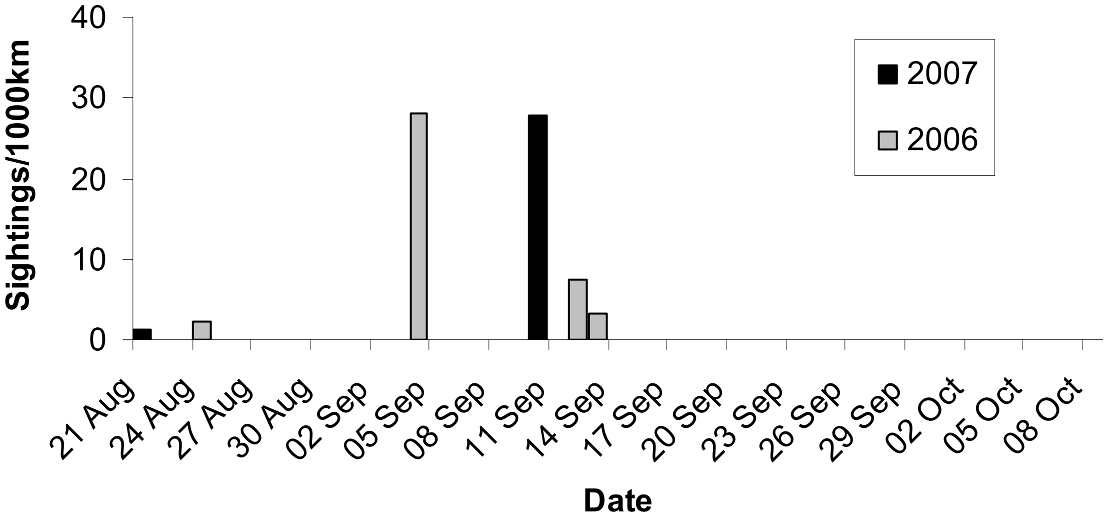


FIGURE 7.16. Beluga whale sighting rates in the central Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. All sightings were non–seismic.

Activities and speed in 2007.— In 2007, belugas were only observed during non–seismic periods and their activities included milling (1 sighting, 13 individuals) and traveling (1 sighting, 2 individuals; Figure 7.17). In addition, all speeds recorded were considered slow.

Activities and speed in 2006.— In 2006, activity was recorded for eight beluga sightings. The majority of recorded activities consisted of traveling (63%) with resting accounting for the remaining 37% of observations. In addition, all speeds recorded were considered slow.

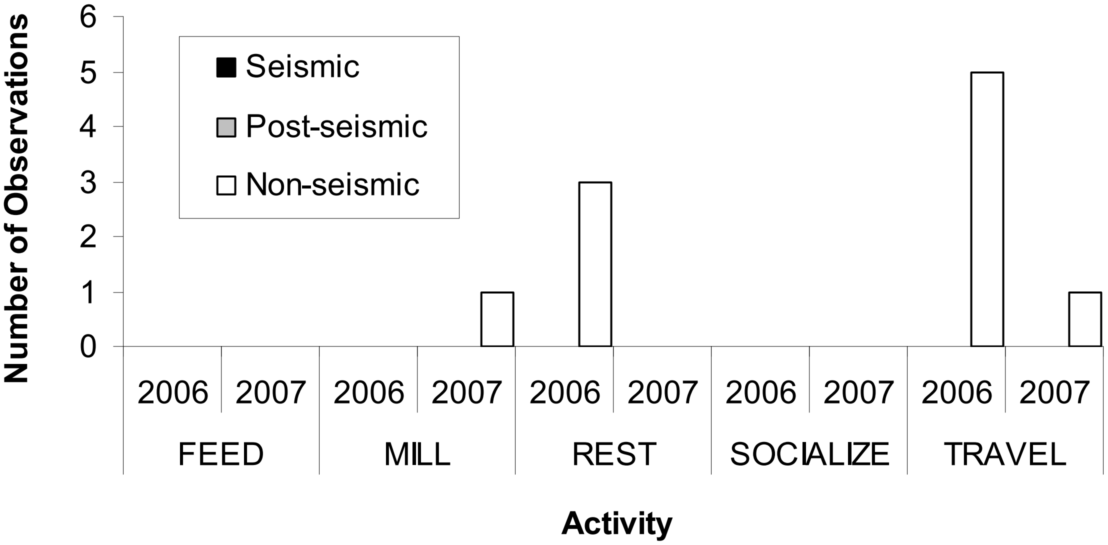


FIGURE 7.17. Observed activities of beluga whales in the central Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Seismic state at time of sighting is indicated by color.

Distances from shore and depth in 2007.—In 2007, beluga sighting rates were highest farther offshore than for bowhead whales with peak sighting rates occurring between 90 and 95 km (56–59 mi) from shore (104.7 sightings/1000 km; 65.0 sightings/1000 mi; Figure 7.18). Patterns for number of individual belugas sighted were similar. Observed whales were located at water depths varying from 100 to 500 m (328–1640 ft), with the majority near 400 m (1312 ft; Figure 7.19). Patterns in depth of individuals sighted were similar, though several large groups were observed at around 50 m (164 ft) deep.

Distances from shore and depth in 2006.—Beluga sighting rates peaked closer to shore in 2006 than 2007. Peak sighting rates were found between 60 and 65 km (37–40 mi) from shore (124.2 sightings/1000 km; 77.1 sightings/1000 mi; Figure 7.18). Belugas often travel in large groups, however. Though when assessed by total number of whales, rather than number of sightings, offshore distribution patterns were similar. Observed whales were located at water depths varying from 100 to 350 m (328–1148 ft), with the majority near 200 m (656 ft; Figure 7.19). Patterns in depth of individuals sighted were similar, though several large groups were observed at around 250 m (820 ft) deep.

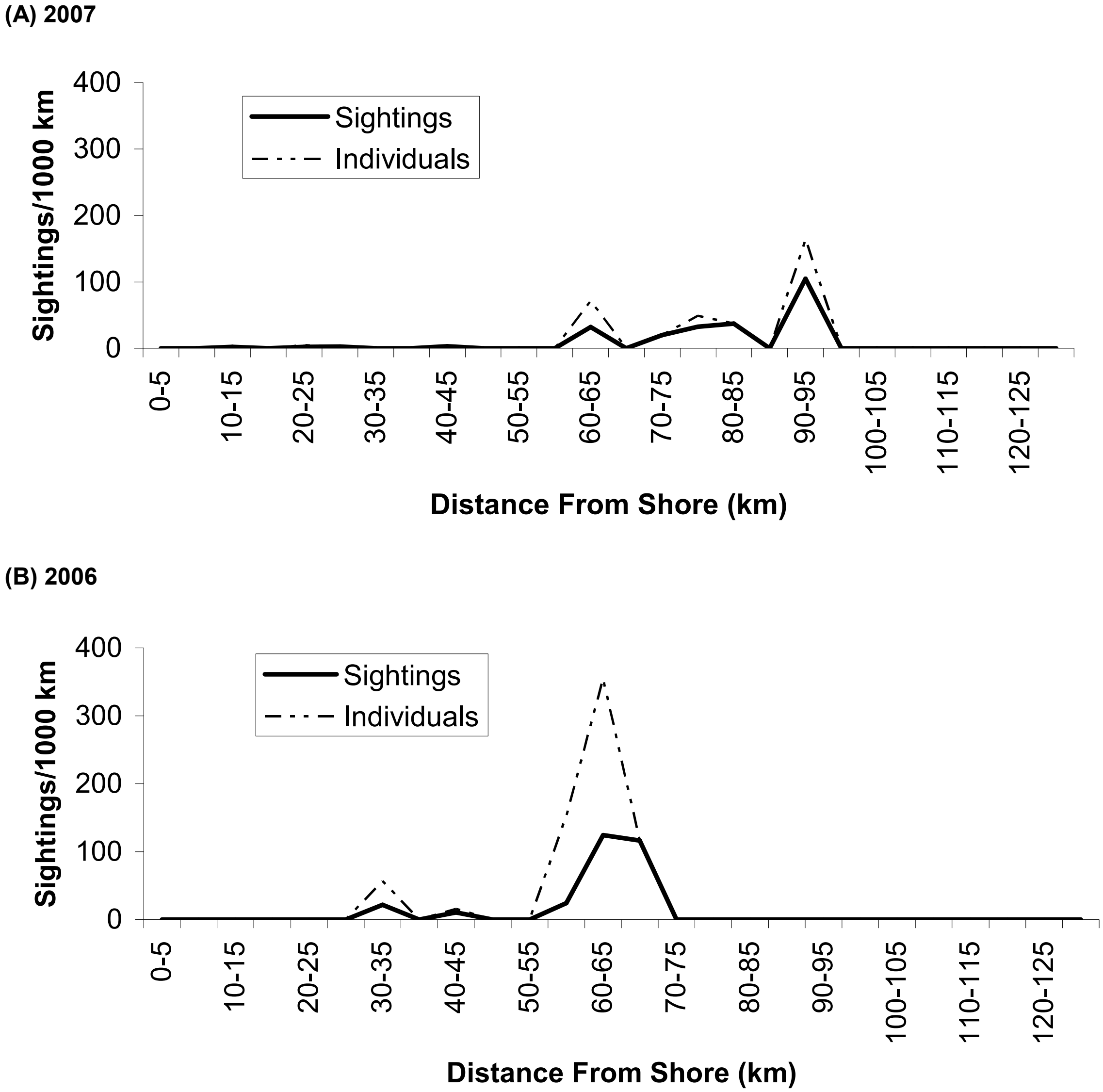


FIGURE 7.18. Beluga whale sighting rates by distance from shore during surveys in the central Beaufort Sea (A) from 22 Aug through 8 Oct 2007 and (B) from 26 Aug through 24 Sep 2006.

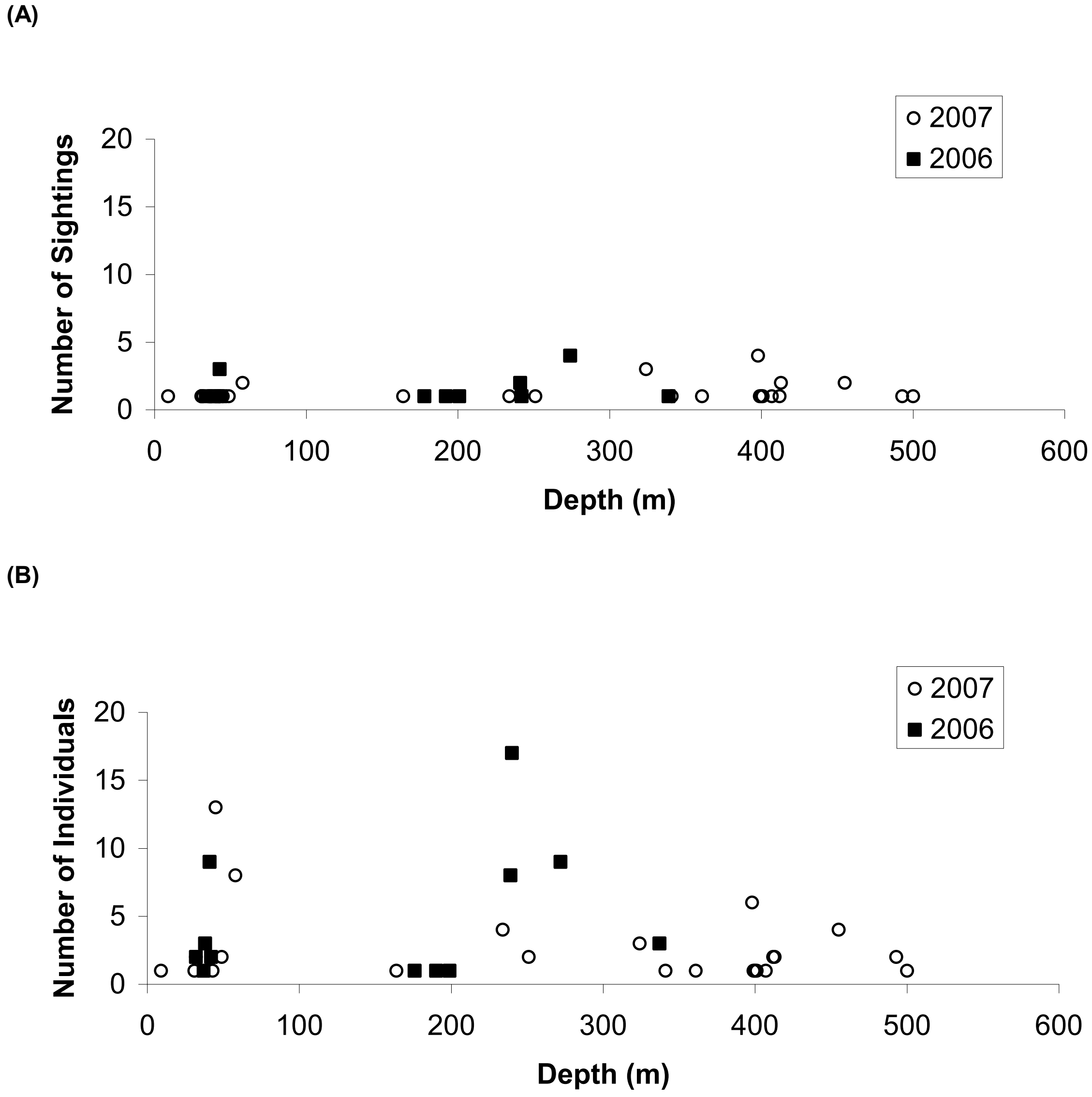


FIGURE 7.19. Water depth at beluga whale sighting locations in the central Beaufort Sea from 22 Aug through 8 Oct 2007 and from 26 Aug through 24 Sep 2006. (A) Number of beluga sightings, (B) number of individual belugas. All sightings were non–seismic.

Gray Whales

No useable gray whale sightings were recorded in 2007, though one unusable sighting was made on 22 Aug 2007. One useable and two non–useable gray whale sightings were made in 2006. Two sightings, including the one useable sighting, were made on 4 Sep 2006; the other sighting was made on 14 Sep 2006 (Figure 7.20).

Humpback Whales

No humpback whale sightings were recorded during our surveys in the Beaufort Sea in 2006 or 2007. However, a reliable sighting of a small group of humpback whales was made east of Point Barrow in mid–Aug 2007 as part of a different study (Green et al. 2007).

Harbor Porpoises

Two useable harbor porpoise sightings were made in 2007. The first sighting was of one animal on 10 Sep while the aircraft was at an altitude of approximately 305 m (1000 ft) and the sighting was calculated to be approximately 1223 m (4012 ft) away. The second sighting was of two individuals traveling at a moderate pace on 18 Sep. Altitude for this sighting was 305 m (1000 ft), and the sighting was calculated to be approximately 363 m (1191 ft) from the aircraft. Although harbor porpoises have not previously been reported in the Beaufort Sea during aerial surveys, the observer on both occasions (Bill Koski) was experienced and sighting conditions were optimal (coded as "1", or "good"; Figure 7.20). Also, harbor porpoises were frequently seen east of Barrow during a bowhead whale tagging study in late Aug and early Sep 2007 (Craig George, pers. comm.).

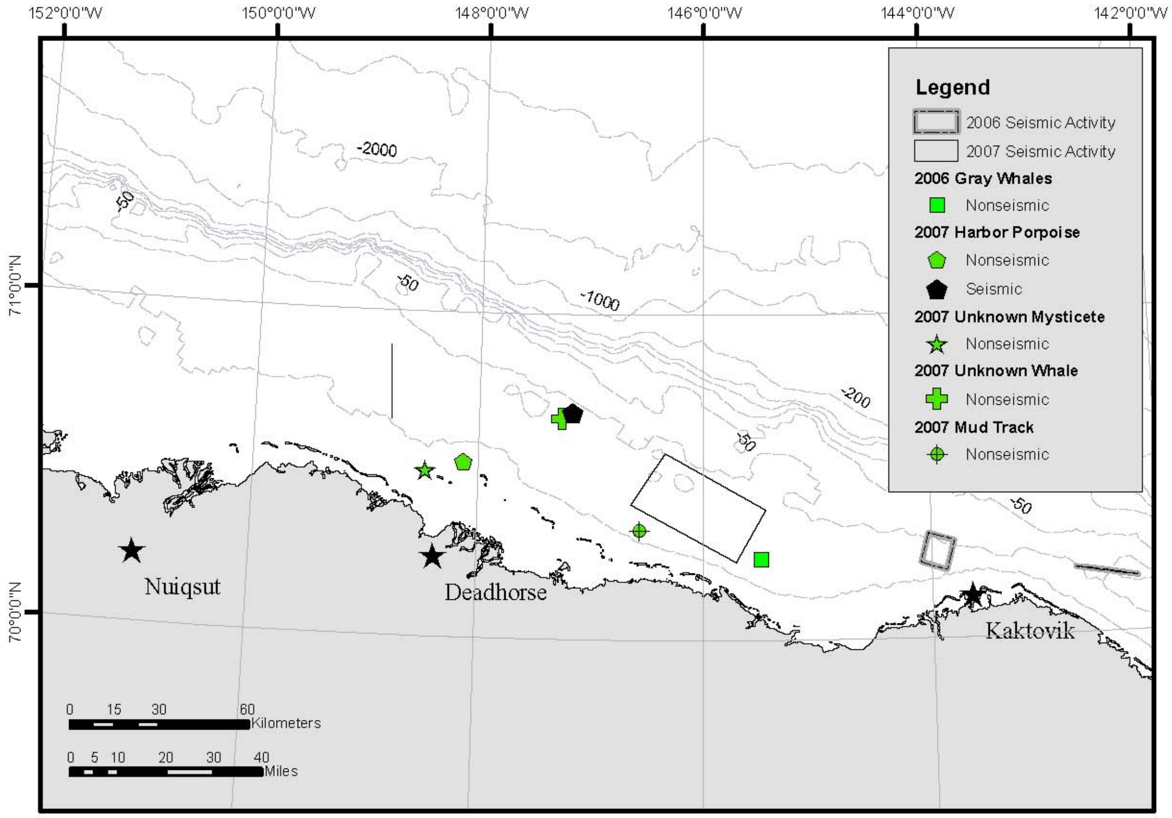


FIGURE 7.20. Gray whale, harbor porpoise and unknown cetacean sightings relative to the seismic prospects in the Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Seismic state at time of sighting is indicated by color.

Seals

A total of 55 useable bearded seal sightings (69 individuals), 145 ringed seal sightings (559 individuals) and an additional 131 sightings (593 individuals) of small, unidentified seals which were likely ringed seals, though possibly spotted seals, were recorded during the aerial surveys conducted in Harrison and Camden bays in 2007 (Figures 7.21 and 7.22). Seals often cannot be reliably identified to species during surveys conducted at 305 to 457 m (1000 to 1500 ft) above sea level. Most seals were recorded when Beaufort wind force was 0 to 2 and few were detected when Beaufort wind force was >2. In 2006, 12 useable bearded seal sightings (14 individuals), 24 ringed seal sightings (29 individuals), 1 spotted seal sighting (1 individual) and an additional 24 sightings of unidentified seals likely to be either ringed or spotted seals, were recorded.

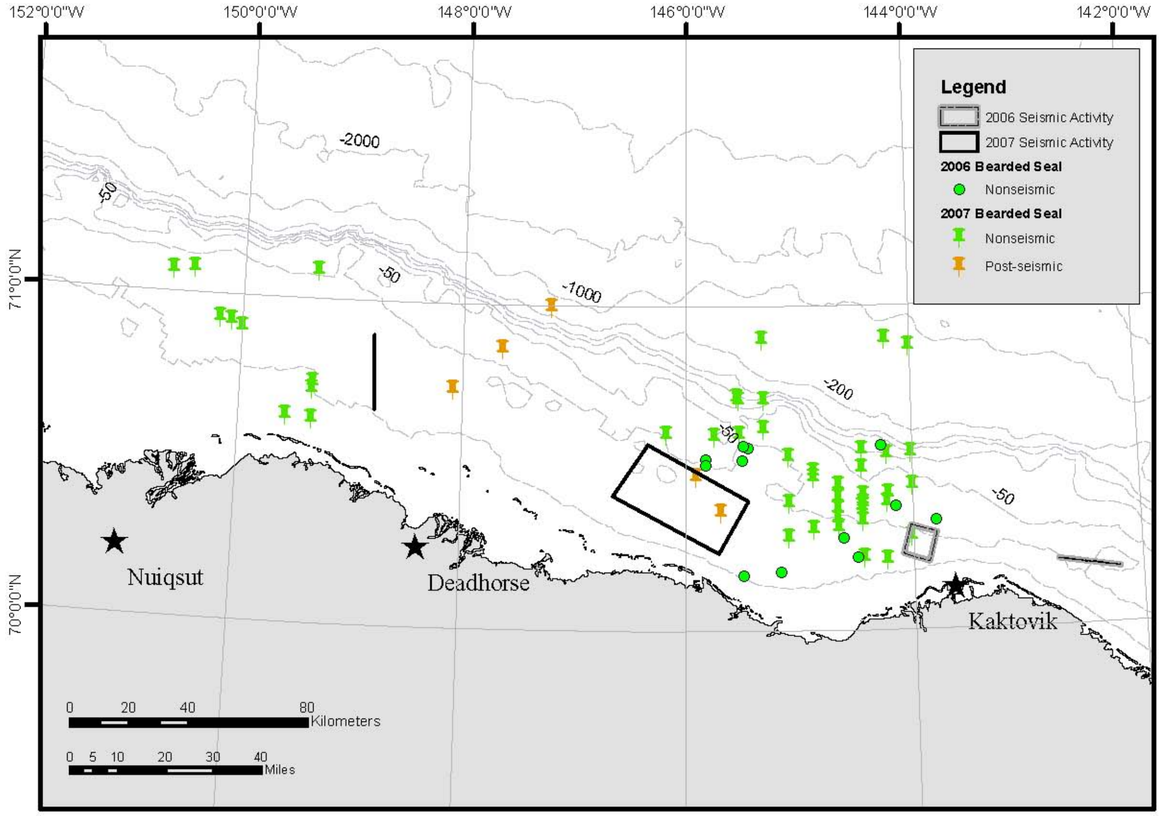


FIGURE 7.21. Bearded seal sightings relative to the seismic prospects explored in the Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Seismic state at time of sighting is indicated by color.

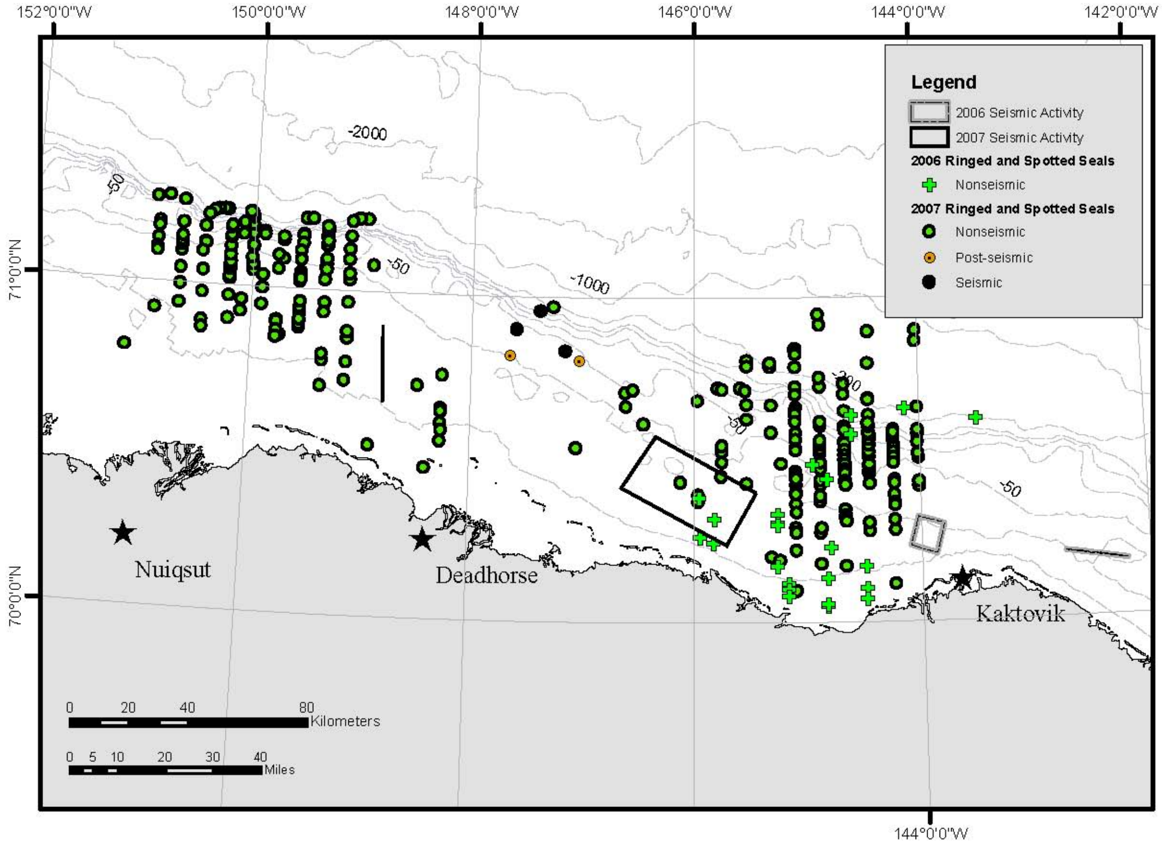


FIGURE 7.22. Ringed and spotted seal sightings relative to the seismic prospects explored in the Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Seismic state at time of sighting is indicated by color.

Polar Bears and Walruses

Twenty–seven polar bear sightings (47 individuals) were recorded during 2007 aerial surveys. None of these sightings were considered useable because all occurred during transit between transects or while traveling to and from the study area (Figure 7.23). These sightings were of 12 lone adults, one sub–adult, nine mother–cub pairs, and five bears of indeterminate age. Of the nine mother–cub sightings, three were of a mother and a lone yearling, three were of a mother and two young–of–the–year cubs, and three were of a mother with two cubs of undetermined age. Resting (71%) and walking (21%) were the primary polar bear activities observed and almost all bears sighted were on barrier islands. In addition, one useable walrus sighting, a cow/calf pair, was recorded in 2007 (Figure 7.23). One useable polar bear sighting (1 individual) and five useable walrus sightings (6 individuals) were recorded in 2006.

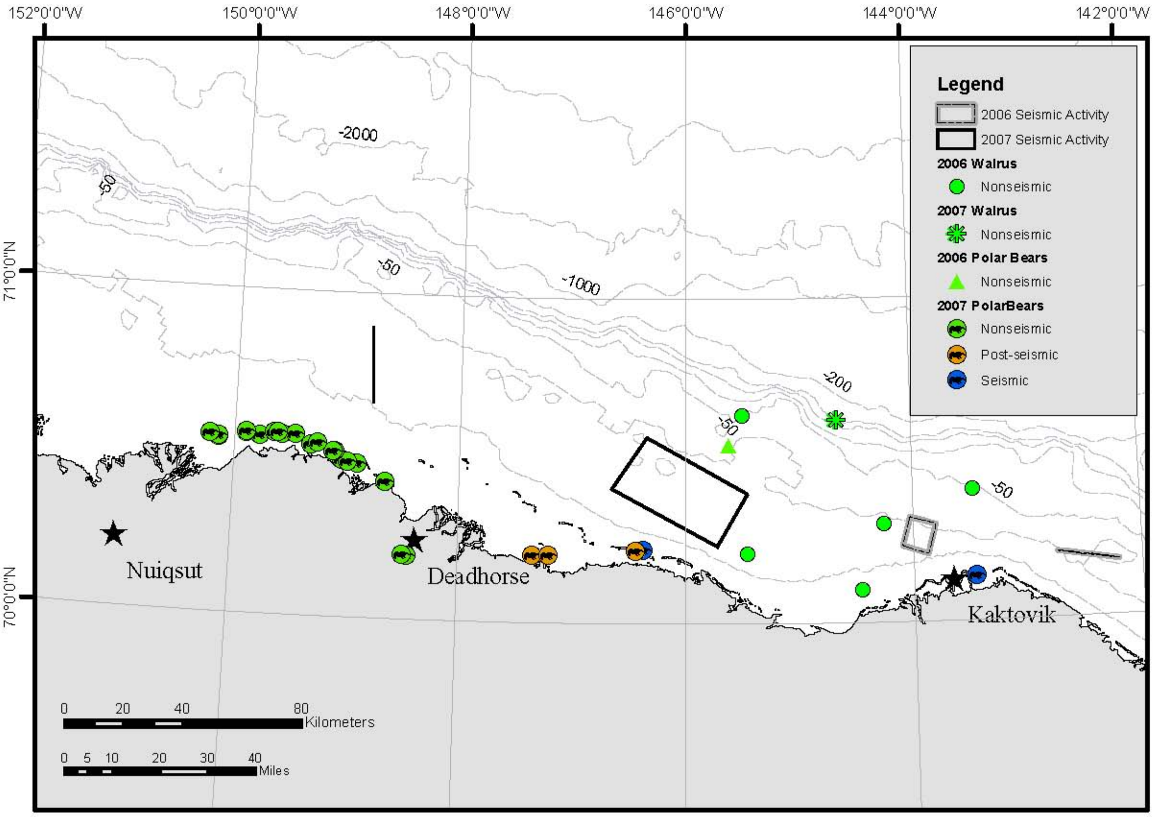


FIGURE 7.23. Walrus and polar bear sightings relative to the seismic prospects in the Beaufort Sea from 26 Aug through 24 Sep 2006 and 22 Aug through 8 Oct 2007. Seismic state at time of sighting is indicated by color.

Summary and Conclusions

Aerial surveys were conducted from late Aug through early Oct 2007 with the majority of effort during non–seismic periods. Survey effort was less in 2006, with no effort during seismic or post–seismic periods. Environmental conditions between years were different with moderate, persistent ice cover in much of the study area throughout late Aug and Sep 2006 and no ice cover throughout the study period in 2007. Overall, patterns in bowhead abundance, distribution, and use of the study area were different between years.

In contrast, overall trends in beluga activity, speed, distance from shore, and sighting rates were consistent between years. Beluga sighting rates were highest in early Sep and the majority of migrating belugas appeared to pass north of our survey area, with peak sighting rates near the shelf break. Beluga activities consisted primarily of traveling at slow speeds or resting. These data are consistent with prior research indicating that belugas spend the majority of their time in the Beaufort Sea along the shelf break or far offshore during fall migration (Treacy 1994; Richard et al. 1997, 1998b).

Typically, bowheads of the Bering–Chukchi–Beaufort stock feed in Canadian waters during the late spring and summer and travel through the Alaskan Beaufort Sea during their spring and fall migration from or toward their wintering areas in the Bering Sea. During the fall migration they occasionally stop to feed, and the most common feeding areas in the Alaskan Beaufort Sea have been found near and east of Kaktovik, and near Point Barrow (Landino et al. 1994; Thomas et al. 2002). In 2006, patterns in bowhead abundance, headings, and migration timing aligned with those found in previous studies (i.e., Miller et al. 1999, 2002; Würsig et al. 2002) with the majority of sightings consisting of north and westward traveling whales, moving at moderate speeds through the study area in pulses, followed by periods of low abundance. The areas where seismic surveys were conducted in 2007 have not been heavily used by feeding whales during earlier years and long–term studies (Miller et al. 2002) have noted relatively low sighting rates of bowheads in these areas, though traditional knowledge indicates that the Flaxman Island vicinity has historically been a bowhead feeding ground. Although considerable variability has been seen in the areas used and the extent of use among years, data collected in the central Alaskan Beaufort Sea during the fall of 2007 showed a different pattern of use of that area than most years, and it is possible that this difference may be linked to the low ice cover extent in 2007. The arrival of bowhead whales from the Canadian Beaufort to waters near Barrow (Goetz 2008) was unusually late in 2007. Small numbers of bowheads thought to be summer Chukchi residents are often seen feeding to the east of Point Barrow by early Sep and numbers usually increase gradually through mid– and late Sep into Oct. In 2007, whales arriving from summering areas to the east appeared to have stopped to feed in the central Beaufort Sea, and hence, did not arrive near Barrow until later than normal, in the last weeks of Sep. Bowhead sighting rates in the central Alaskan Beaufort Sea remained high throughout early to mid–Sep, with no significant evidence of migratory headings, and a high proportion of the whales sighted apparently engaged in feeding. Additionally, the majority of sightings consisted of individuals categorized as moving slowly. Migrating whales tend to travel at moderate speeds (Würsig et al. 2002) and whales that have been disturbed often travel at fast speed. Thus data on speed of movements suggest that many of the whales sighted during our surveys were lingering in the area or feeding.

This interpretation is supported by the high frequency of observations of apparently feeding whales. Feeding activity was interpreted from observations of behaviors such as moving slowly and without consistent westerly (i.e., migratory) headings, turning at the surface followed by diving, open mouths and presence of mud splotches on bodies, indicating epibenthic feeding. Feeding and travel activities are considered common summer and fall behaviors in the eastern Alaskan Beaufort Sea (Würsig et al. 2002), but in general, feeding is believed to be more common there than in our 2007 study area

(Thomas et al. 2002). Also of interest was the trend for bowheads observed in the eastern part of our survey area to have a more westward direction of travel than those observed in the central and western areas, suggesting that more feeding was occurring near and west of Sivulliq than elsewhere in Camden Bay.

Previous studies (LGL and Greenridge 1987; Richardson et al. 1999; Schick and Urban 2000) have indicated that certain types of seismic and drilling noise can cause migrating bowheads to deflect from their typical migration route; however, studies from the summer feeding area suggest that bowheads are much more tolerant of seismic operations when an attractant such as food is present (Miller et al. 2005). These observations are supported by our data. High sighting rates were observed near seismic operations and these sightings consisted primarily of whales that appeared to be engaged in feeding as opposed to migratory activities.

Also interesting was the trend of sighting rates by distance from shore among seismic areas. While there were no significant differences among geographic areas, slight trends indicated that peak sighting rates occurred farther offshore during seismic activity in the central area than in eastern and western areas, at a distance offshore roughly corresponding to that of the seismic prospect. Rather than being displaced by seismic operations, bowheads appeared to have aggregated in the vicinity of operations, though on average, bowhead distance from the center of the Sivulliq prospect in Camden Bay increased very slightly during periods of active seismic work which suggested some avoidance did occur. These observations lend support to the idea that feeding bowheads are more tolerant of seismic activities than are migrating whales. It also suggests that whales may not be deflected as far from seismic operations as previous studies have indicated (i.e., Miller et al. 1999), because had they deflected at those distances, whales would not have known that food resources were present west of Sivulliq. It is possible, however, that deflection did occur at the distances observed by Miller et al. (1999) and that bowheads observed near the seismic operation may have arrived there before seismic operations began, remaining despite seismic operations. More research is needed to determine the influences of potential food resources or other biological factors on bowhead whale distribution and movements when potential sources of disturbance are present. Also, in the case of feeding whales, using sound exposure levels (Southall et al. 2008) instead of assuming behavioral takes may be a more appropriate method of calculating bowhead "take" estimates because they appear to be more tolerant of industrial sounds when feeding.

Large differences in environmental parameters, bowhead whale distribution, and whale activities between 2006 and 2007 made pooling data for these two years inappropriate. In general, however, timing of peak abundances were similar between 2006 and 2007 and were consistent with migrational patterns observed during previous studies (i.e., Miller et al. 2002), though higher sighting rates were seen in 2006 and 2007 than the average rates of earlier studies (Miller et al. 2002). Trends in predominant activities and offshore distribution, however, were less in accordance with results from previous research. Feeding was much more common than expected in 2007 and this trend was potentially linked to environmental differences. Distance from the center of the seismic survey area did not differ significantly by seismic state (P=0.481), though a minor shoreward displacement in bowheads west of the seismic operation was observed in 2007. These apparent shoreward movements, however, may have been associated with feeding aggregations of whales near Cross Island. Further credence is lent to this idea by the fact that offshore distribution of bowheads did not change between seismic and non–seismic periods in the central area where seismic activity was being conducted. Previous research (Treacy et al. 2006) indicated that offshore distribution of bowhead whales may vary with ice cover, leading whales to move farther offshore in heavy ice years. With evidence of such a strong environmental influence contributing to offshore bowhead distribution, it is difficult to assess the affects of seismic activity on offshore distribution.

Additional research assessing the interactions between ice cover and bowhead behavior and distribution would help future studies in identifying changes due to anthropogenic verses environmental parameters.

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8. BEAUFORT SEA ACOUSTIC MONITORING PROGRAM[1]

INTRODUCTION

During the open-water season of 2007, Shell Offshore Inc. (SOI) planned to conduct both seismic surveys and drilling in the Beaufort Sea. Marine mammal monitoring was known to be required for all such marine work in the Alaskan Arctic, particularly with respect to the possible influence of underwater sounds on bowhead whales and effects on the native whale hunts. To provide information on bowhead migration paths along the Alaskan Beaufort Sea coast with respect to these industrial operations, Greeneridge Sciences, Inc., in collaboration with JASCO Research, Inc. and Shell, put together a study plan relying principally on passive acoustics with directional autonomous recorders.

Objectives

The objective of this study was to provide information on migration paths of bowhead whales along the coast of the Alaskan Beaufort Sea in late summer and early fall in relation to Shell's industrial operations, and to determine whether and to what extent there were differences in the distribution of calling whales as a function of industrial sound levels. Using a passive acoustics method based on arrays of directional autonomous recorders and triangulation (Greene et al. 2004), the locations of calling whales were observed for a six- to seven-week continuous monitoring period at five coastal sites. The 2007 field season lasted from 20 August to 12 October and the data collected are presented in this report.

METHODS

Equipment

Recordings were made using 35 **D**irectional **A**utonomous **S**eafloor **A**coustic **R**ecorders model B07 (DASAR-B07). The recorder design was a modified version of the DASAR-Bs of 2006 (see Greene et al. 2004; 2007). A DASAR-B07 will hereafter be referred to simply as a "DASAR". A picture and schematic representation of such a DASAR are shown in Figure 8.1. The DASAR consists of a pressure housing (7" high and 12.75" in diameter, or 17.8 cm × 32.4 cm, respectively) containing the recording electronics and alkaline batteries. A sphere suspended elastically about 5" (12.7 cm) above the pressure housing includes three-axis geophone elements for the directional sensors and a flexural pressure transducer for the omni-directional sensor. The pressure housing is bolted to a weighted square frame with 30" (76 cm) sides. A spandex "sock" stretched over the tubular "cage" surrounding the pressure housing (see Fig. 8.1B) protects the sensors from motion in water currents. The total in-air weight is 62.7 lb (28.4 kg) and the in-water weight is 38.5 lb (17.5 kg).

DASARs record sound at a 1 kHz sampling rate (1000 samples/s) on each of four data channels: (1) an omnidirectional channel, (2) a "cosine channel" on the primary horizontal axis, (3) a "sine channel" on the horizontal axis perpendicular to the cosine channel, and (4) a vertical channel perpendicular to both

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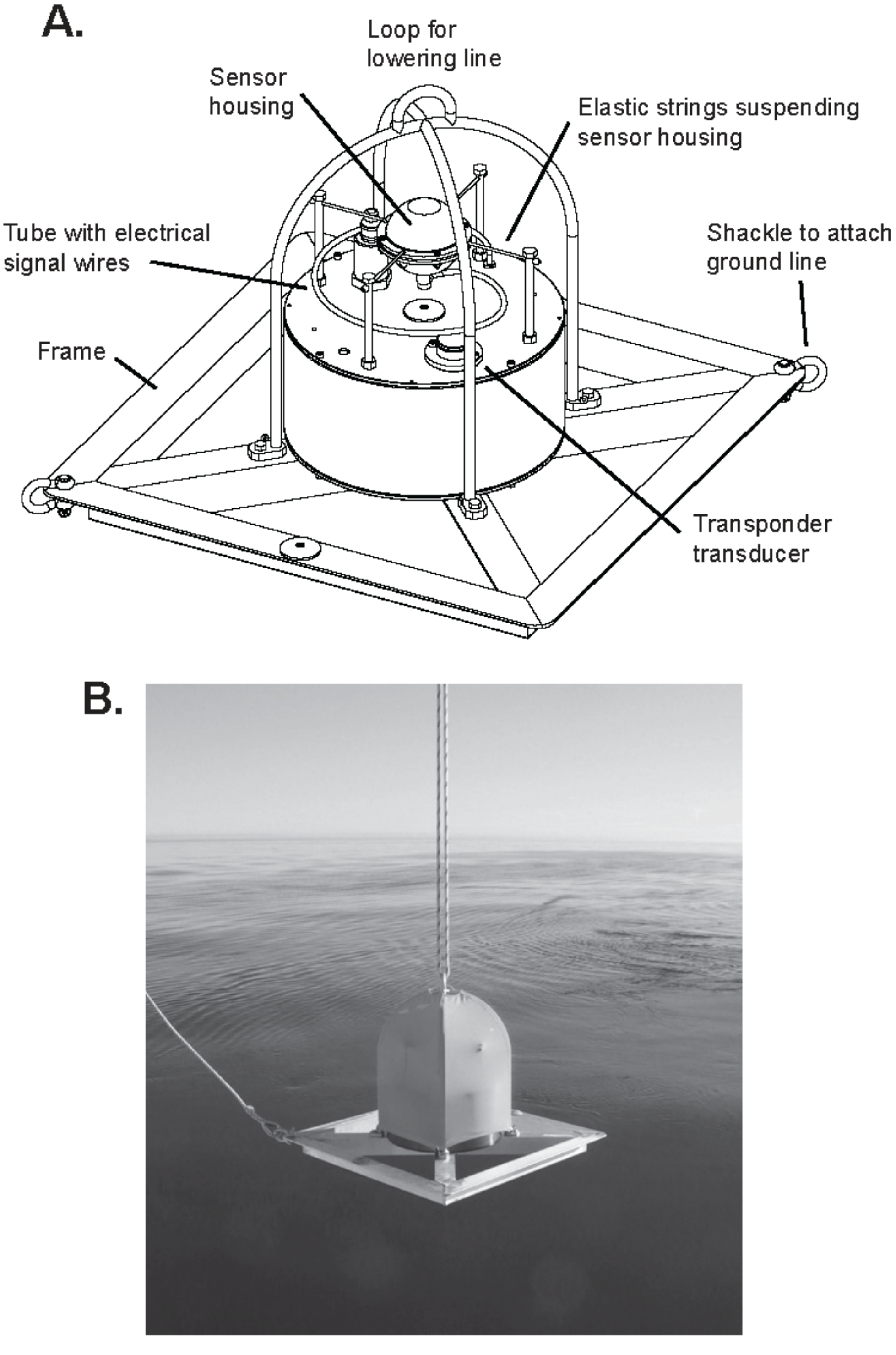

FIGURE 8.1. DASAR recorder (model B07). ***(A)*** Schematic diagram of the components of the DASAR-B07 recorder. ***(B)*** A DASAR about to be deployed off the stern of the *Norseman II*, in ideal weather conditions. The lowering line is looped through the top of the frame and is removed after the DASAR is set on the ocean floor. The 100-m ground line (off to the left in the picture) is connected to a chain and Danforth anchor, which are deployed last.

horizontal channels. Each channel has maximum sensitivity in its primary direction; sensitivity falls off with cosine of the angle away from the axis. Each recorder has a signal digitizer with 16-bit quantization. The samples are buffered, and periodically (every ~45 min) written to an internal 60 GB hard drive. Allowing for anti-aliasing, the 1 kHz sampling rate allows for 60 days of continuous recording and an acoustic bandwidth of 450 Hz.

DASAR Hydrophone Calibration

The omnidirectional hydrophone in each DASAR, an acoustic pressure sensor, was used for sound pressure measurements of the background, whale calls, and airgun pulses. These hydrophones were procured with information from the manufacturer permitting their individual sensitivities to be computed. In addition, two DASARs were taken to the U.S. Navy's sound transducer calibration facility on Seneca Lake, New York, for calibration.

The two DASARs calibrated at Seneca Lake were then used as secondary standards for comparison with the remaining DASARs. A plywood box sufficiently large for two DASARs was constructed with a loudspeaker at one end. The box served to isolate the subject DASAR hydrophones from the local room noises and to permit accurate positioning of the DASARs within the box. Two calibration methods were used: (1) Measure the response in the box of a calibrated DASAR from Seneca Lake, and then substitute an "unknown" DASAR and repeat the measurement, comparing the two results to determine the sensitivity of the "unknown". (2) Put a calibrated DASAR from Seneca Lake in the box next to an "unknown" DASAR, run the calibration transmission, and compare the results of the "known" and "unknown" DASARs to calibrate the "unknown". These two methods gave the same results within 0.5 dB, and the comparison of the two "known" DASARs, treating one of them as the "unknown", yielded similarly close results to those obtained at Seneca Lake.

The sensitivity based on the manufacturer's data was expected to be -150 dB re 1 V/µPa and the results of the Seneca Lake calibration demonstrated a sensitivity of -149 dB re 1 V/µPa. The hydrophone recorder electronics in the DASARs overloaded (saturated) when the instantaneous sound pressure exceeded 153 dB re 1 µPa. Such overloading occurred with some of the received airgun pulses.

Field Procedures

DASARs were installed on the seafloor with no surface expression, which is important to avoid entanglement with ice floes. One corner of the DASAR frame was attached with a shackle to 100 m of "ground line", which ended with 1.5 m (5 feet) of chain and a small Danforth anchor. During deployment the DASAR was lowered onto the seafloor using a line passed through the loop at the top of the "cage" (see Fig. 8.1B). One end of the lowering line was then released from the vessel and the line was retrieved. The vessel then moved away from the DASAR location while laying out the ground line in a straight line. As the end of the ground line was reached the Danforth anchor was dropped into the water. GPS positions were obtained of both the DASAR and anchor locations.

To retrieve the DASARs a 30-foot (9.1 m) chain fitted with grapnel anchors was dragged over the center of the ground line and perpendicular to it. The grappling line was deployed off the stern of the *Norseman II*, the ship from which all the fieldwork was done. To ensure the chain and grapnels were dragging on the seafloor and not "flying" behind the vessel (off the seafloor), a ~20 kg (44 lb) weight was added at the junction between the grappling line and the chain. Figure 8.2 illustrates the method, which is simple but effective: the crew of the *Norseman II* caught DASARs on the first pass in over 90% of cases.

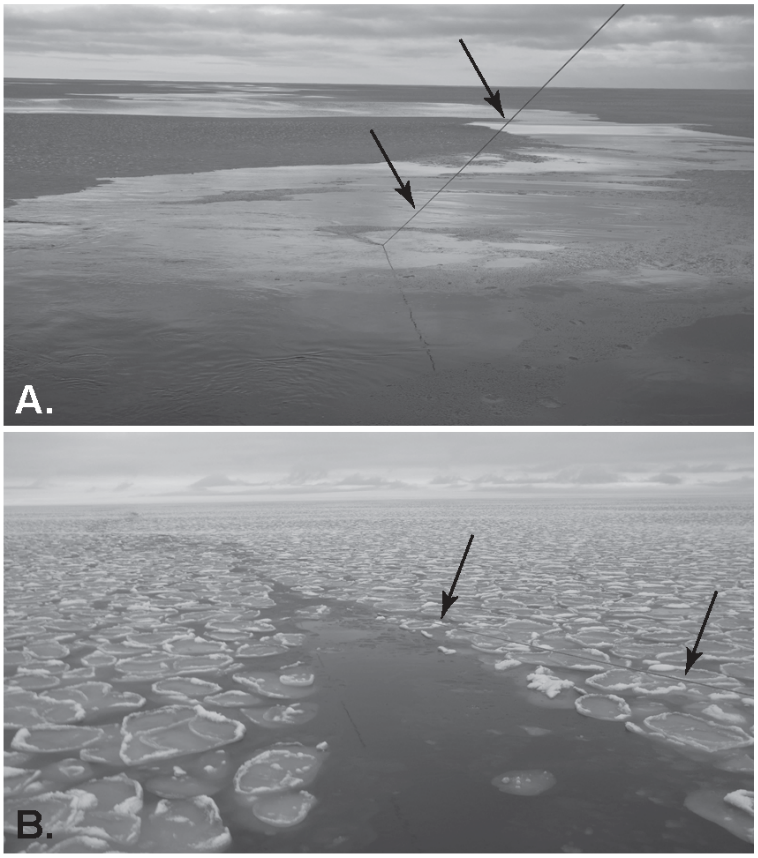

FIGURE 8.2. Grappling procedure, as seen off the stern of the *Norseman II*. The black arrows point to the grappling line. The pancake ice in ***(B)*** required a lower angle while dragging the grapples behind the vessel.

Deployments

DASAR deployments took place on 20–24 August 2007. Figure 8.3 shows that DASARs were deployed in five groups ("sites") of seven recorders, spread over an alongshore distance of ~280 km (151 n.mi. or 174 mi) offshore of Alaska's North Slope. The easternmost site was north of Barter Island, and the westernmost site was in Harrison Bay. Table 8.1 summarizes this information for all 35 DASARs. The seven DASARs at each site were placed to form a north-south stack of five equilateral triangles with 7 km sides (Fig. 8.3). The southernmost DASARs were 15–33 km (8–17.8 n.mi. or 9.3–20.5 mi) due north of the coast, and each group of seven DASARs extended northward by 21 km (11.3 n.mi. or 13 mi) from the southernmost DASAR. DASAR locations at each site were labeled A, B, C, D, E, F, and G, from south to north. Water depths at deployment locations were in the range 15–54 m (49–177 feet) and are summarized in Table 8.1. Deployments were done from south to north, starting at the easternmost site 5 and heading west to sites 4, 3, 2, and 1.

Clock and Bearing Calibrations in the Field

When DASARs are lowered to the seafloor there is no way to control their orientation in relation to true north. In addition, each DASAR contains a clock that has a small but significant drift, which needs to be measured and compensated for over the course of the deployment period (Greene et al. 2004). Field

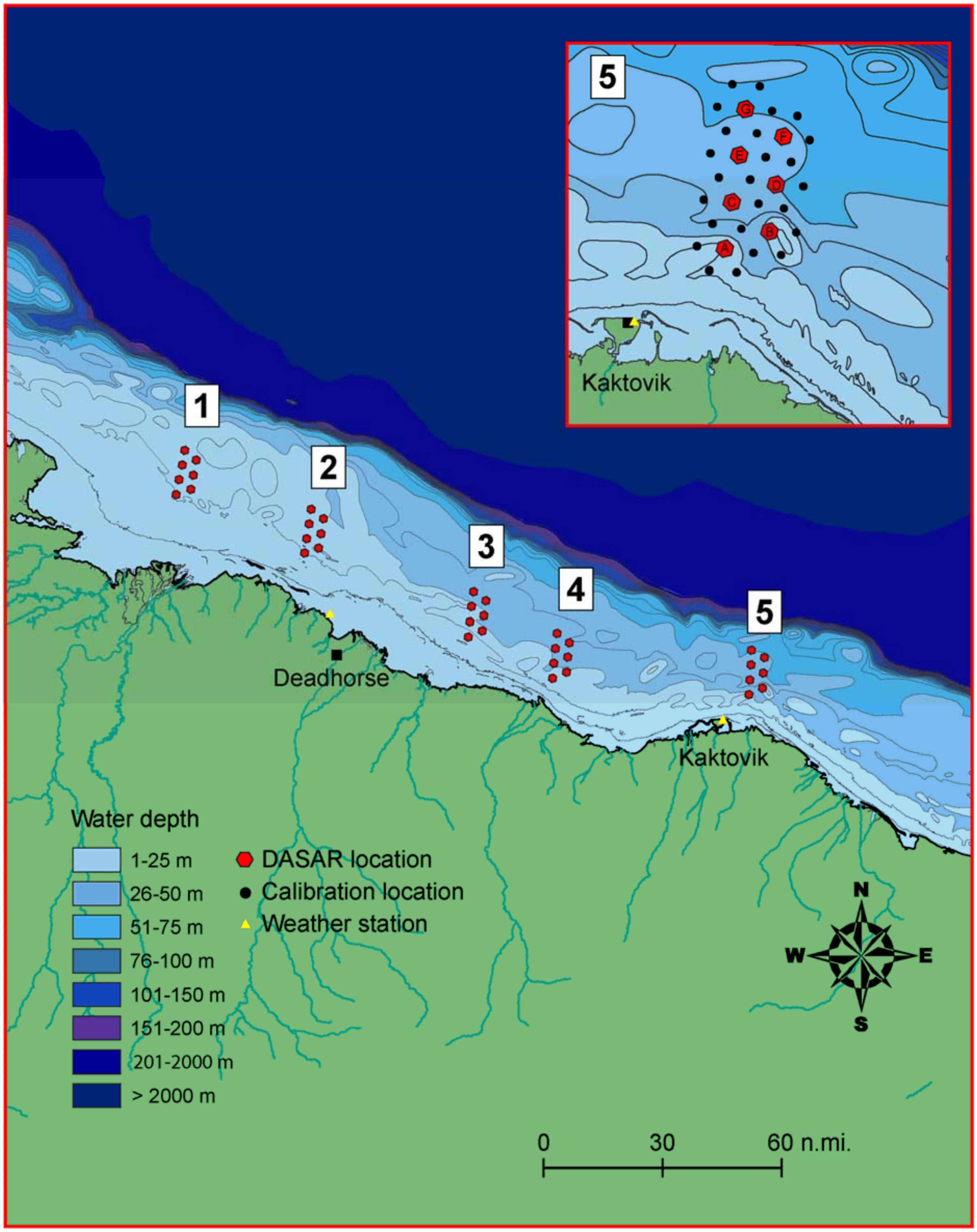

FIGURE 8.3. DASAR deployment locations during the 2007 field season (azimuthal equidistant projection). The five sites are labeled 1–5 from west to east, and the seven DASARs at each site are labeled A–G from south to north (see insert). The insert shows how 25 calibration locations were placed in relation to the DASARs at site 5. The same relative calibration locations were used at each site.

TABLE 8.1. Deployment and retrieval dates in 2007, deployment locations (WGS84) and water depth for DASARs deployed for Shell during the 2007 open-water season. Duplicate positions (e.g., $3G_1$ and $3G_2$) are those at which a DASAR was retrieved in mid-season and redeployed. DASARs 1D, 1E, and 1F were not retrieved before freeze-up in Oct. 2007 and were collected in August 2008. DASAR 1G was also not retrieved before freeze-up in 2007 but was not found in Aug. 2008, and is therefore considered lost.

Site	Position	DASAR #	Latitude (deg. N)	Longitude (deg. W)	Depth (m)	Deployment date	Retrieval Date
1	A	35	70.7910	150.6573	21.9	24 Aug.	12 Oct.
1	B	31	70.8232	150.4895	23.2	24 Aug.	12 Oct.
1	C	33	70.8549	150.6574	23.8	24 Aug.	12 Oct.
1	D	30	70.8865	150.4890	23.8	24 Aug.	17 Aug. 08
1	E	32	70.9178	150.6519	21.9	24 Aug.	17 Aug. 08
1	F	34	70.9494	150.4907	23.8	24 Aug.	17 Aug. 08
1	G	1	70.9806	150.6562	14.6	24 Aug.	Lost
2	A	24	70.6385	148.9513	21.9	23 Aug.	11 Oct.
2	B	27	70.6699	148.7863	24.4	23 Aug.	11 Oct.
2	C	29	70.7014	148.9522	24.7	23 Aug.	11 Oct.
2	D	28	70.7309	148.7854	28.3	23 Aug.	11 Oct.
2	E	26	70.7644	148.9524	26.8	23 Aug.	11 Oct.
2	F	25	70.7949	148.7838	31.7	23 Aug.	11 Oct.
2	G	23	70.8271	148.9526	31.7	23 Aug.	11 Oct.
3	A	21	70.3853	146.8022	29.0	22 Aug.	8 Oct.
3	B	20	70.4171	146.6422	33.5	23 Aug.	8 Oct.
3	C	19	70.4490	146.8029	33.2	23 Aug.	8 Oct.
3	D	16	70.4809	146.6401	38.1	23 Aug.	8 Oct.
3	E	17	70.5122	146.8039	38.7	23 Aug.	8 Oct.
3	F	22	70.5441	146.6393	39.0	23 Aug.	8 Oct.
3	G_1	18	70.5752	146.8016	40.5	23 Aug.	18 Sept.
3	G_2	18	70.5747	146.8036	40.5	18 Sept.	8 Oct.
4	A	8	70.2510	145.7210	27.7	22 Aug.	10 Oct.
4	B	6	70.2825	145.5610	31.7	22 Aug.	10 Oct.
4	C	3	70.3142	145.7222	32.0	22 Aug.	10 Oct.
4	D	2	70.3449	145.5600	34.7	22 Aug.	10 Oct.
4	E	7	70.3773	145.7232	37.2	22 Aug.	10 Oct.
4	F	4	70.4071	145.5594	40.5	22 Aug.	10 Oct.
4	G	5	70.4401	145.7231	40.8	22 Aug.	10 Oct.
5	A	9	70.2463	143.3142	38.7	20 Aug.	9 Oct.
5	B	11	70.2769	143.1528	46.9	20 Aug.	9 Oct.
5	C	14	70.3088	143.3145	47.5	21 Aug.	9 Oct.
5	D_1	10	70.3408	143.1543	52.4	21 Aug.	18 Sept.
5	D_2	10	70.3409	143.1531	52.4	18 Sept.	9 Oct.
5	E_1	13	70.3731	143.3131	53.6	21 Aug.	18 Sept.
5	E_2	13	70.3729	143.3121	53.6	18 Sept.	9 Oct.
5	F	15	70.4059	143.1514	53.3	21 Aug.	9 Oct.
5	G	12	70.4354	143.3147	53.6	21 Aug.	9 Oct.

calibrations consisted of projecting test sounds underwater at known times and known locations, and recording these sounds on the DASARs. After processing, the collected data allowed us to determine each DASAR's orientation on the seafloor, so the absolute direction of whale calls could be obtained. The calibration transmissions also allowed us to synchronize the clocks from various DASARs, so that the bearings from a call heard by more than one DASAR could be combined, allowing an estimate of the caller's position by triangulation. Calibration transmissions were projected at six locations around each DASAR, at a distance of about 4 km. This resulted in a total of 25 calibration locations for each site. The insert in Figure 8.3 shows the locations of these calibration stations for site 5.

Equipment used for calibrations included a J-9 sound projector, an amplifier, a computer to generate the projected waveform, and a GPS to control the timing of the sound source. The projected waveform consisted of a 2-s tone at 400 Hz, a 2-s linear downsweep from 400 to 200 Hz, a 2-s linear upsweep from 200 to 400 Hz, and a 2-s linear downsweep from 400 to 200 Hz. Figure 8.4 shows a spectrogram of this waveform. The source level of the projected sounds was ~150 dB re 1 µPa @ 1 m. An entire waveform transmission required 8 s, and there were 7 s between two consecutive waveforms, which initiated every 15 s. A total of nine waveforms (taking a total of 2 min 15 sec) were transmitted from each calibration station. Calibration of one entire site took 8.5 hours in good weather conditions. Each site was calibrated directly following the deployment of its seven DASARs, and at the end of the season before retrieval (see below).

Mid-season Health Checks

To insure that the recorders and their software were functioning as expected, a health check was performed on each DASAR in mid-season (14–21 Sept.). A surface-deployed transducer (a pole-mounted Benthos DRI-267A Dive Ranger Interrogator) was placed in the water at the recorded GPS location of each DASAR. The transducer interrogated an acoustic transponder (Benthos UAT-376, operational range 25–32 kHz) in each recorder, which responded on one frequency if it was recording and on another frequency if it was not. The DASAR at location 3G passed its health check but was retrieved as a precaution, to check that it was indeed recording data normally. It was reprogrammed and redeployed immediately (Table 8.1). DASARs at locations 5D and 5E were retrieved because they failed their health checks. DASAR 5D never started recording after deployment, and DASAR 5E recorded properly but had a faulty transponder. Refurbished or reprogrammed instruments were immediately redeployed at both locations (Table 8.1).

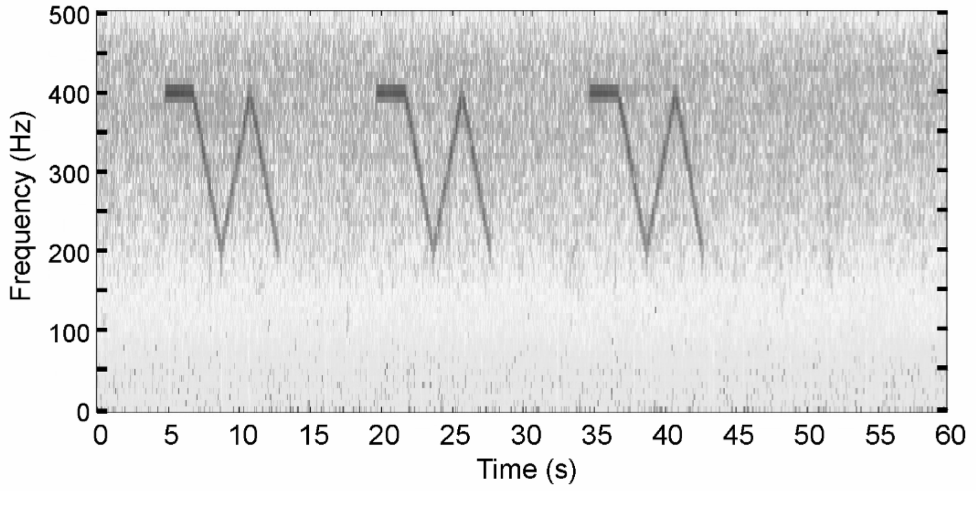

FIGURE 8.4. Spectrogram of three calibration waveforms as used in 2007.

Retrievals

Retrievals were scheduled to begin on 5 Oct, but weather conditions did not allow transfer of personnel to the *Norseman II* until 7 Oct. Retrievals took place on 8 to 12 Oct. Site 3 was retrieved first. To save on travel time, retrievals were done by alternating between calibrations and grappling sessions: for example, after completing the six calibrations surrounding DASAR 3A, the DASAR itself was retrieved. DASAR 3B was retrieved after completion of another four calibrations (two of DASAR 3B's calibration locations are in common with DASAR 3A, see insert in Fig. 8.3), and so on until all instruments were brought onto the ship. Before departing the site, an "overwintering DASAR" was redeployed at location 3D. This DASAR was loaded with special duty-cycling software that led it to record on the omnidirectional channel for about 35 minutes every three hours. This duty-cycling should go on for approximately 10 months, until the batteries are depleted. Overwintering DASARs were also deployed at locations 5D, 4D, and 2D. Table 8.2 summarizes the deployment information for the four overwintering DASARs, which will be retrieved during the redeployments in summer 2008.

After completion of site 3 the *Norseman II* traveled overnight to site 5, which was calibrated and retrieved on 9 Oct. The southernmost third of the site was covered with small pancake ice. Site 4 was calibrated and retrieved on 10 Oct. The southern end of site 4 was covered in large pancake ice (see Fig. 8.2B) and travel was slow for the *Norseman II*. Both sites 4 and 5 were completely or partially frozen over a few days later. Site 2 was calibrated and retrieved on 11 Oct., in increasingly poor sea state and wind conditions, with pancake ice at the southern end transitioning to "apple sauce" at the northern end. On 12 Oct. retrievals were started at site 1. Waters were ice-free but sea state was 3–4 (wave height up to 2.4 m or 8 ft). DASARs 1A, 1B, and 1C were retrieved with incomplete calibrations. Retrievals were then called off as sea state continued increasing, reaching sea state 6 (wave height up to 6 m or 20 ft) later that night. The *Norseman II* headed NW, then SW and S and reached Nome on 16 Oct. DASARs at position 1D, 1E, 1F, and 1G were left in place over the winter. Three of these DASARs (1D, 1E, and 1F) were retrieved the following year, on 17 Aug. 2008; the last one (1G) was never found despite several attempts at locating it.

Data Analysis

After retrieval, the DASARs were opened up and dismantled. The sampling program was shut down, and the 60 GB hard drives were removed and hand-carried back to Greeneridge headquarters where they were backed up. Data were transferred to computers running MATLAB and custom analysis software.

Time and Reference Axis Calibration

As explained in the section *Clock and Bearing Calibrations in the Field* (above), the field calibrations were designed to provide data allowing us to calibrate the DASAR clocks and to determine each DASAR's orientation on the seafloor.

Time Calibration.—The DASAR sample clock is fairly accurate, and the cold and reasonably stable temperature on the seafloor maintains a constant clock drift rate. Nevertheless, the clocks will incur a linear drift that, over 30 or 40 days of deployment, can reach ± one min, varying among DASARs. For each set of calibrations, directly following deployment and preceding retrieval of the instrumentation, a program predicted the time of arrival for each waveform, allowing for sound propagation through the water along the known distance from calibration site to DASAR, and then measured the actual time. The scatter in these measurements was usually less than one sec. The time error was then characterized as a linear function, shown in Figure 8.5, and used to convert the times as measured by the DASAR clock to absolute time.

TABLE 8.2. Deployment dates, deployment locations (WGS84), and water depths for overwintering DASARs deployed in October 2007.

Site	Position	DASAR #	Latitude (deg. N)	Longitude (deg. W)	Depth (m)	Deployment date
2	D	2	70.7325	148.7874	28.3	11 Oct.
3	D	20	70.4804	146.6419	38.1	8 Oct.
4	D	15	70.3452	145.5529	34.1	10 Oct.
5	D	22	70.3408	143.1520	52.1	9 Oct.

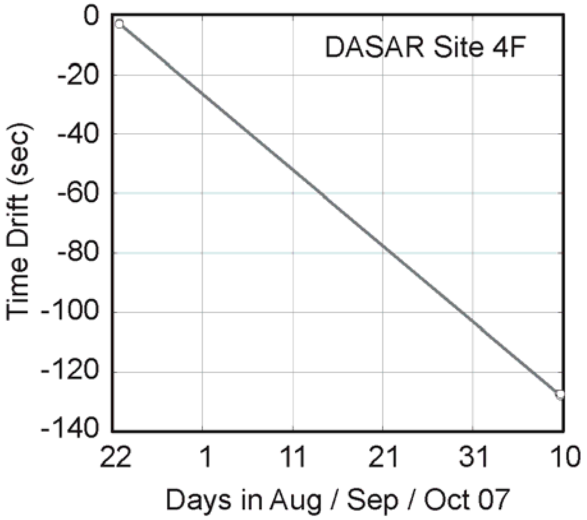

FIGURE 8.5. Clock drift as determined for DASAR 4F, based on the differences between the DASAR's clock and actual time during calibrations on 22 August and 10 October (white circles).

Reference Axis Calibration.—Using spectrograms such as the one shown in Figure 8.4, an operator drew a box (using a computer mouse) enclosing the waveform, thereby defining a start and end time, plus the lowest and highest frequencies. A custom-written MATLAB program then took the three time series (from the omnidirectional, cosine directional, and sine directional channels) between those times, filtered them through a bandpass filter (200–400 Hz), and calculated two new time series:

$$Ia(t) = cosch(t) \cdot omni(t) \qquad \text{Eq. (1)}$$

$$Ib(t) = sinch(t) \cdot omni(t) \qquad \text{Eq. (2)}$$

where *cosch(t)* is the cosine directional channel time series, *sinch(t)* is the sine directional channel time series, and *omni(t)* is the omnidirectional sound pressure time series.

The *cosch(t)* and *sinch(t)* time series are proportional to particle velocity and the *omni(t)* time series is proportional to acoustic pressure. The products (*Ia(t)* and *Ib(t)*) are proportional to acoustic intensity, a vector quantity with magnitude and direction. It is the directional component we measure for each calibration transmission sound and each whale call.

Figure 8.6A shows an example of such a time-series plot, referred to as a scatterplot, with *Ib(t)* on the x-axis and *Ia(t)* on the y-axis. This example is for a calibration transmission. The plot gives a clear

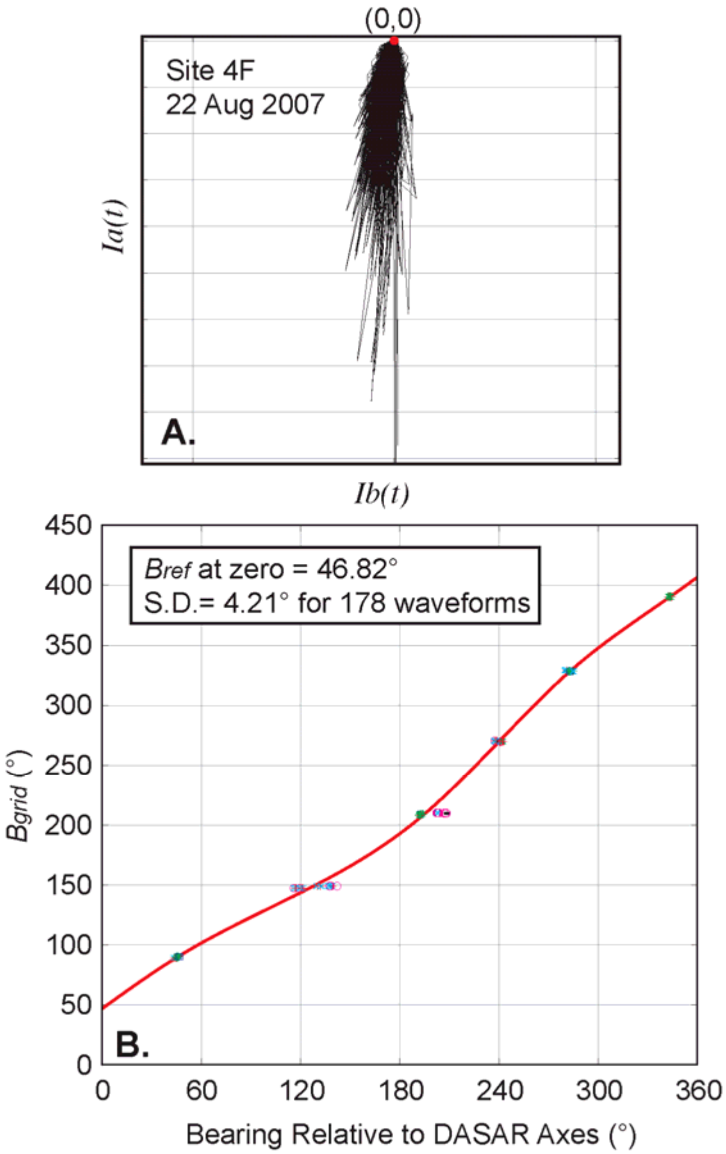

FIGURE 8.6. ***(A)*** Example of a scatterplot of successive bearings for a calibration transmission. See text for details. ***(B)*** Graph relating the measured relative bearing of a sound (whale call) to the grid bearing for that sound. The graph is derived from fitting measured relative bearings of calibration transmissions from six known locations around the DASAR (shown as six groups of symbols along line) to the known (GPS-derived) grid bearings of the transmission source. The standard deviation (S.D.) shown is the average S.D. of all six groups combined.

sense of direction relative to the origin at (0,0). The bearing is computed by separately averaging the *Ia* and *Ib* series over the duration of the sound and taking the arctangent of their ratio:

$$B_{\mathrm{rel}} = arctan\ (Avg(Ia)/Avg(Ib)) \qquad \text{Eq. (3)}$$

where B_{rel} is the bearing of the sound source relative to the DASAR axes, *arctan* is an implementation giving answers in the range 0–360°, and *Avg* denotes the average. In Figure 8.6A the measured B_{rel} is about 192°.

The measured B_{rel} and B_{grid} (the absolute bearing of the source from the DASAR, measured by GPS positions of the sound projector and the DASAR) were averaged, with weights proportional to their respective signal to noise ratios, for 6 groups corresponding to the six calibration positions surrounding the DASAR (see insert in Figure 8.3). The six groups were then fitted to a curve using a spline function and written to a table of B_{grid} versus B_{rel} tabulated every degree. An example of such a curve is shown in Figure 8.6B. During whale call bearing measurements, B_{rel} was rounded to the nearest degree and B_{grid} was read from the table. In theory the function should be a straight line with a slope of 1, but interfering noise and other possible perturbations caused deviations.

Whale Call Analysis

Analysis of the whale calls was done manually by trained staff. Identification and classification of each whale call was done by examining spectrograms of the acoustic data, one minute at a time, and listening to recordings of each call or suspected call. All DASARs belonging to one site (i.e., seven recorders) were analyzed simultaneously. The lead analyst performed regular checks for consistency among analysts. Most calls were detected by more than one DASAR, but each call was classified and tallied only once. Reception of the call at more than one DASAR allowed for triangulation of the call's estimated position, according to a method described in Greene et al. (2004). Calls were classified into three major categories, ***simple calls***, ***complex calls***, and ***call sequences***, on the basis of call descriptions by Clark and Johnson (1984), Würsig and Clark (1993), and Blackwell et al. (2007). ***Simple calls*** were frequency modulated tonal calls or "moans" in the 50–300 Hz range. We distinguished (1) ascending or "up" calls ("/"), (2) descending or "down" calls ("\"), (3) constant calls ("—"), and (4) inflected calls ("∪", "∩", and variations thereof). ***Complex calls*** were infinitely varied and included pulsed sounds, squeals, growl-type sounds with abundant harmonic content, and combinations of two or more simple and complex segments. Subcategories of complex calls could not be consistently discerned, so all subcategories were pooled. ***Call sequences*** were repeated utterances, usually every 2–5 s, of a simple or complex call. Sequence duration ranged from less than one minute to many minutes.

In addition to sounds from bowhead whales, acoustic records included sounds produced by bearded seals (*Erignathus barbatus*), Pacific walruses (*Odobenus rosmarus divergens*), and perhaps ringed seals (*Phoca hispida*).

Machine-Aided Call Detection

Experience analyzing bowhead whale calls for the BP Northstar migration monitoring project (e.g., Blackwell et al. 2007) indicated that machine-aided methods might improve efficiency and perhaps also objectivity. Having to look at the acoustic data to detect whale calls—minute by minute for every day—required considerable time even during periods without whale calls, which sometimes extended as long as 20 hours. A process of machine-aided call detection could reasonably be expected to flag likely calls and to bypass periods without calls. The objective was to use a computer to examine the omnidirectional sound pressure data from each DASAR and detect the presence of a whale call, thereby generating an event file that would cue the analysts to confirm and process the call or to reject the call and move on to the next event, which could be many minutes in the future.

The major challenges to machine-aided detection of bowhead calls arise from the variability of bowhead calls (see *Whale Call Analysis* section above), and the presence of calls from other species, such as bearded seals or walruses. Even though most of these calls are fairly well-defined, there are enough combinations and variations of the basic spectral shapes that any approach based on stereotypical calls would be inappropriate. A second problem is interference from vessels and airgun pulses used in seismic surveys. Vessel sounds are distinctive in that they are generally continuous, unlike bowhead calls. Seismic surveys are pulsive and have energy distributed over our entire analysis band of 10–450 Hz. Most importantly, they occur at consistent intervals. The pulse interval is most often between 10 and 15 seconds, but during some deepwater surveys the interval can be more than 20 s. Conversely, for shallow-penetration surveys, the pulse interval can be less than 5 s.

During analysis of the 2007 data Dr. Aaron Thode (Scripps Institution of Oceanography) developed machine-aided call detection software, which was used by the whale call analysts in parallel with manual analysis of the calls. The approach taken was to use a four-pass algorithm[2] to examine the raw sound data files from Greeneridge. At an early point in the call analysis, the algorithms were missing 22% of the calls and the false detection rate was 75%. These performance figures were improved, by the time the 2007 analysis ended, to a miss rate of less than 10% and a false detection rate of about 40% for days with no airgun activity.

The benefit of machine-aided call detection was very small, in 2007, because the call detection rates were unexpectedly high—there were few periods without whale calls, so machine-aided call detection did not speed up analysis. In a situation with fewer calls and longer periods without whale calls, the machine-aided procedure would be of more benefit. Nevertheless, the software served as a launching pad for automated call detection, which will be used in 2008 as an integral part of the whale call analysis. In addition to improved call detection and false detection rates, automated call detection will include call type classification and automatic localization, by matching detections across DASARS at a given site.

Whale Call Localization

Bearings to calling whales were determined for each of 7 DASARs at sites 2–5 (Figure 8.3). Beyond identifying and tallying whale calls, no further analyses were done at site 1 since that site was incomplete until August 2008. When two or more of the seven DASARs at a given site detected a given call, the location of the calling whale was estimated using triangulation. This section describes this triangulation method, which was designed to provide both an estimated location and an error estimate.

When a call occurred, each DASAR receiving the call provided a directional bearing, with some uncertainty, to the call (Greene et al. 2004). We used the Huber robust triangulation location estimator (Lenth 1981; Greene et al. 2004) to compute call locations based on the intersection(s) of bearings from multiple DASARs within a site. The Huber estimator downweighted the occasional outlying bearing and in theory yielded a more robust and accurate location solution than alternative techniques. Calls received by a single DASAR could not be localized. Calls could have been detected by only 1 DASAR, or missed completely, if the call was weak, occurred far from the DASAR array (due to attenuation of the signal), or occurred during times when background levels of underwater ambient sound were high (mainly due to high wind and wave action). Even when calls were received by ≥2 DASARs they occasionally did not produce a location estimate because estimated bearings either did not cross or were too disparate to allow the Huber estimator to converge.

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[2] (1) Energy detection; (2) interval removal, designed to remove airgun pulses; (3) contour tracing and/or image segmentation; and (4) feature extraction and filtering.

For each call location, an uncertainty ("error") estimate in the form of a 90% confidence ellipse was calculated using the methods in Lenth (1981). Confidence ellipse size was based on the number of DASARs that received the call, the configuration (geometry) of all pair-wise bearing intersections, disparity of the intersections, and inherent variation estimated from calibration data for each DASAR (Greene et al. 2004). Area (m^2) and lengths (m) of the major and minor axes were computed for each ellipse.

The logarithm of error ellipse size generally increased at a constant rate with the logarithm of the distance to the closest DASAR until a certain distance was reached (Fig. 8.7). Beyond that distance, the rate of increase in error ellipse size was more rapid. The distance at which error ellipse size began to increase rapidly was deemed the distance within which we could reliably locate calls. Although there was some variation in this distance, it was in the range 5–8 km at all sites. To include as many calls as possible, yet not include calls whose estimated locations were unreliable, we excluded calls beyond 10 km from the nearest DASAR for certain types of analyses.

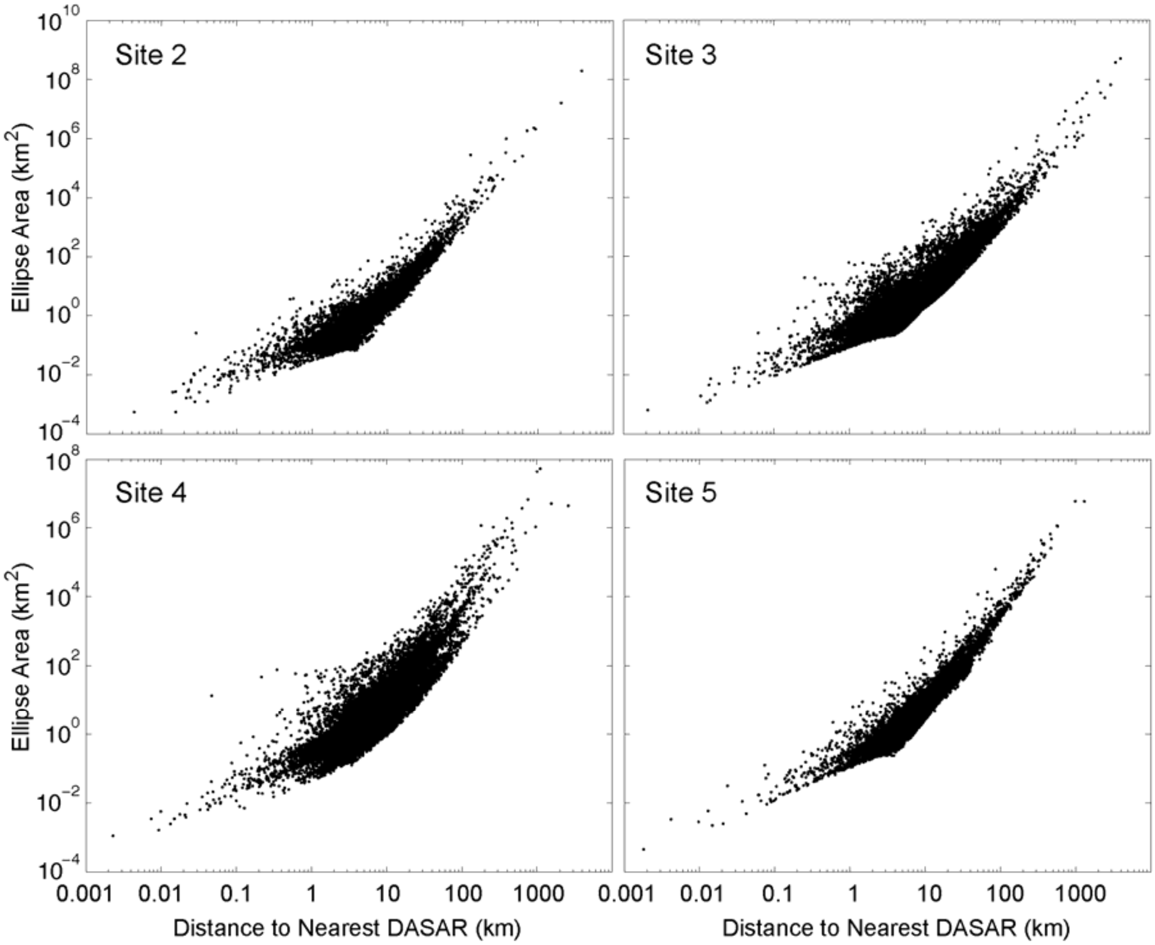

FIGURE 8.7. Area of the 90% confidence ellipse for all estimated locations as a function of distance from the nearest DASAR for sites 2, 3, 4, and 5. Note that area increases more rapidly with distances beyond 5–8 km.

Call Detection Rates as a Function of Seismic Activity

Seismic activities by Shell took place during 18 Sep–3 Oct, a period of 15.3 days, at a location between sites 3 and 4 (see Fig. 8.11, later, and Chapter 2). We compared the total number of whale calls obtained at sites 3 and 4 during this period of seismic activity with the total number of calls during the 15.3 days directly preceding the onset of seismic activities. However, this simple comparison did not take into account several important confounding factors. For example, wind speed is correlated with ambient sound levels, which in turn may mask whale calls. Wind speed may not have been the same before and during seismic activity. Another factor is the seasonal fluctuations in the number of migrating whales. To address these concerns another approach was taken, described below.

The hourly rate of whale calls with estimated locations was calculated at each of the four sites with complete data sets (sites 2, 3, 4, and 5) during each of three periods defined as ***before***, ***during***, and ***after*** seismic operations (see Chapter 2 for the schedule of seismic operations). We refer to the hourly rate of whale calls with estimated locations as the "call location rate", to distinguish it from the overall call detection rate, which includes calls with and without position estimates. The dates and times at which DASAR monitoring began and ended varied among the 4 sites. Therefore, the ***before*** and ***after*** periods were defined to be the same at all sites. The ***before*** period began when DASAR monitoring was initiated at the site where DASARs were last deployed (site 2 on 23 August), and ended right before the onset of seismic operations. The ***before*** period did not include a brief interval of seismic testing on 8 August 2007 (see Fig. 8.13, later). The ***during*** period included the four longest intervals of continuous seismic survey operations, but did not include the intervening intervals when airguns were not firing. The ***after*** period started right after the end of seismic operations and ended when monitoring was terminated at the site where monitoring ended earliest (site 3 on 8 Oct). Most of the seismic operations took place at a location between sites 3 and 4, so these were designated as sites *near* seismic operations, whereas sites 2 and 5 represented sites *far* from seismic operations (see Fig. 8.3).

The analysis was designed to compare call location rates at the two groups of sites (*near*, *far*) across the three periods (***before***, ***during***, ***after***) using a systematic sample of one-hour intervals throughout the DASAR monitoring study. To begin, a time point was randomly selected from within the first six hours of the ***before*** period, and then successive time points were systematically selected every six hours. Each time point represented the onset of a one-hour sample interval. This procedure was intended to ensure independence of samples, based on previous analyses of temporal dependencies in bowhead whale calling (McDonald et al. 2008). Only those one-hour intervals that were entirely within one of the three periods (***before***, ***during***, ***after***) were retained for analysis. The number of calls was tallied within each one-hour interval, by site and by period. The count data generated by the sampling were analyzed using the Poisson regression model

$$\ln(\#\,calls) = \beta_0 + \beta_1 group + \beta_2 period + \beta_3 group \times period \qquad \text{Eq. (4)}$$

where *group* represented sites either near or far from seismic operations. Our interest centered on the *p*-values of the $group \times period$ interaction and several associated linear contrasts. In particular, the interaction term was examined via a likelihood ratio test comparing the deviances of the full model (including the interaction term) and the reduced model (excluding the interaction). Linear contrasts addressed differences between pairs of periods across the 2 groups (e.g., whether the change in number of calls from ***before*** to ***during*** was the same for the *near* and *far* groups). All contrasts were examined using Wald chi-square tests (Wald 1943). In addition to the Poisson regression, simple averages of hourly counts were calculated for each site and period.

The process described above—generation of a systematic sample (with random start) of 1-hour intervals, tallying of whale call positions within intervals (calls that were detected but not located were ignored), estimation of the Poisson regression model, and storage of results—was repeated 1000 times. Results were summarized by calculating the proportion of *p*-values that exceeded 0.05, independently for the overall interaction and each associated contrast. Each such proportion was itself interpreted as a *p*-value (weight of evidence with respect to the null hypothesis of no effect). Separate analyses were conducted for whale calls with estimated locations within 10 km of the nearest DASAR and for all calls, irrespective of distance to estimated location. Furthermore, to guard against potential dependence between samples taken every 6 hours, additional analyses were conducted with samples taken every 12, 18, and 24 hours. For plotting purposes, the bootstrap distribution of average hourly counts for each site and period was summarized by calculating a grand mean (an average of averages) and confidence limits were obtained using the percentile method (Manly 2007).

Airgun Pulse Characteristics and Background Sound

Airgun pulses from the Shell surveys and from other unrelated surveys were received by the DASARs at all five sites in the Beaufort Sea. The received levels were computed from the recorded data at the A units (closest to shore) and at the F or G units (at the northern end of each array) at sites 2–5.

The machine-aided call detection routines described in a previous section included software for detecting airgun pulses in the recorded acoustic data—specifically the data from the omnidirectional pressure sensor. Detection was based on the broad bandwidth and consistent inter-pulse intervals of the received signals. Once detection was achieved, it was straightforward to have the computer measure the instantaneous peak pressure (in dB re 1 μPa) and the corresponding sound pressure level (SPL, in dB re 1 μPa), and sound exposure level (SEL, in dB re 1 $\mu Pa^2 \cdot s$) of each pulse. Pulse duration was determined using the method of integrating the received pressure squared over the pulse and noting the 5% and 95% times of the accumulated "energy" (Malme et al. 1986; Blackwell et al. 2004; Southall et al. 2007).

To characterize the ambient (non-pulsive) background sound over time, SPLs were computed and averaged for every two seconds at all the DASAR sites. Then, for every ten-min interval, the minimum SPL value over that interval was selected. This effectively excluded times when airgun pulses or other transient sounds were present.

The DASARs were designed for the generally low levels of received sounds from bowhead calls and background noises, not for the high amplitudes of nearby airgun pulses. In fact, the DASARs overloaded (the recorded signal was distorted) when the instantaneous peak pressure exceeded 153 dB re 1 μPa. Such levels occurred when the distances from the airgun array were on the order of 25 km or less. Note that the 153 dB overload level is an instantaneous peak pressure and that, in our experience, the corresponding sound pressure levels (RMS over pulse duration) average about 12 dB less than the peak levels (Greene 1997). Thus, an instantaneous peak of 153 dB should correspond to an SPL magnitude of about 141 dB re 1 μPa above which overloading would be expected.

Received Levels of Seismic Pulses at Whale Call Locations

To investigate the distribution of received seismic pulse levels that bowhead whales were subjected to during their 2007 migration through the study area, we calculated the received level (SPL) of airgun sounds at each whale call location. Four pieces of information were used for these calculations:

(1) The position of the airgun array as a function of time. This was provided in "gun logs" by the seismic operators. When these logs were found to be incomplete, they were

supplemented by ship navigational data and by positional data recorded by the Marine Mammal Observers (MMOs) stationed on each vessel.

(2) The operational state of the airgun array when in use, i.e., whether only one gun or the full array was firing. This information was also obtained from a combination of gun logs and MMO observations. A single database of position and seismic operational state was created for one-minute intervals throughout the entire period of seismic survey operations. This was done by sub-sampling the gun logs—in which data were automatically recorded at 2–10 s intervals—and interpolating MMO position fixes (separated by irregular intervals of several minutes to several hours).

(3) The estimated position of the whale. Whale position could only be estimated when a whale vocalized and that vocalization was detected by two or more DASARs at the same site. The uncertainties in estimation of whale location are discussed in the section ***Whale Call Localization*** above.

(4) Propagation equations to allow calculation of estimated received levels. We used the equations provided by JASCO Research, Inc., based on their sound source verification (SSV) measurements in 2007 (Funk et al. 2008[3]). These equations were of the form

$$Received\ Level\ (RL) = A - B\times\log(range) - C\times range \qquad \text{Eq. (5)}$$

Table 8.3[3] lists the A, B, and C coefficients provided by JASCO for the two vessels involved (*Gilavar* and *Henry Christoffersen*), the state of the seismic array (number of guns), and whether the formula applies to the near-field or the far-field.

Received levels (RL) were calculated using two methods based on different assumptions about whale exposure to seismic sounds. ***(1) "Concurrent" method:*** each whale call occurring during seismic operations was matched to the position and operational state of the airgun array at the closest point in time. ***(2) "Full array" method:*** the greatest source of uncertainty in RL calculations lay in the estimated location of the calling whale. Necessarily, there was even greater uncertainty in a whale's location at times when it was not calling. Nonetheless, we reasoned that as a whale moved through the area where a seismic vessel was operating, the whale would likely at some point in time have been exposed to sounds from the full array. We therefore calculated the RL at the whale's estimated position using only the full array propagation equations (24 guns for *Gilavar*, 2 guns for *Henry Christoffersen*), though we recognize that at the time the full array was actually operating the whale may have been either closer to or farther from the seismic ship – and therefore the actual RL may have been either greater than or less than the calculated value.

Received levels were calculated for all calls with a position estimate. The data were then analyzed using either all calls or only those whose locations were within 10 km of the nearest DASAR. Histograms of received level were generated and summary statistics were calculated for each of these conditions. To assess whether there were differences in mean RL among the four sites, a one-way analysis of variance (ANOVA) was conducted. An associated linear contrast was constructed to compare the mean of the two sites near seismic operations (sites 3 and 4) with the mean of the two sites far from seismic operations (sites

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[3] Most of the coefficients shown in Table 8.3 were updated by JASCO Research Inc. after the publication of the Funk et al. 2008 report, so they will differ from what is presented in Funk et al. 2008.

TABLE 8.3. A, B, and C coefficients used in the calculations of received levels (SPL, in dB re 1 µPa) of airgun pulses at whale call locations.

		Near field (< 1 km)			Far field (≥ 1 km)		
Ship	# guns &/or date	A	B	C	A	B	C
Gilavar[1]	24 guns[2]	245.200	19.9000	0.00041	245.200	19.9000	0.00041
Gilavar[1]	1 gun[3]	217.900	19.9000	0.00041	217.900	19.9000	0.00041
Henry C.	2 guns, 30 Aug.	208.679	17.5187	0.00240	265.884	36.0772	0.00044
Henry C.	1 gun, 30 Aug.	199.659	15.8268	0.00250	223.298	23.3992	0.00200
Henry C.	1 or 2 guns, 14, 17, 18 Sept.[4]	184.219	6.8582	0.00540	232.061	24.5661	0.00022

[1] For *Gilavar*, the same equation was used for the near field and far field. [2] Endfire equation. [3] This is the 24-gun equation with the intercept (A coefficient) adjusted downward for the reduced number of guns. [4] The same equation was used for 1 and 2 guns for the *Henry C.* in September (no equation was obtained for a single gun).

2 and 5). To account for potential temporal and spatial dependencies in the whale call data, the statistical significance of the overall ANOVA and the linear contrast were assessed using block permutation (Lahiri 2003). Blocks were constructed using cluster analysis based on the estimated whale call times and UTM coordinates. This approach for dealing with dependencies in whale call data was based on that developed and described in detail by McDonald et al. (2008). Calls were clustered using an agglomerative method until the Moran's I correlation coefficient between clusters or blocks reached 0. For the ANOVA, blocks of the response variable (RL) were randomly permuted 5000 times. With each permutation, the overall F statistic and the contrast t statistic were calculated and stored. The randomization distribution of F (and t) was compared to the F_0 (and t_0) statistic based on the original (not permuted) data. The p-value for each test was calculated as the proportion of randomized test statistics that exceeded the original test statistic.

Quantile Regression of Whale Call Locations

Quantile regression (Koenker 2005; McDonald et al. 2008) was used to estimate the distribution of calling whales within 10 km of the nearest DASAR at each of the four sites for which we had complete data sets. Conceptually, quantile regression estimates a regression equation for quantiles (i.e., percentiles) of a response variable's distribution. In contrast, regular regression estimates a regression equation for the mean of a response variable's distribution. This section summarizes the quantile regression analyses used to estimate the distribution of detected calls around each array through time.

To estimate the distribution of calling whales through time, quantile regression related the northing coordinate of every call location to smooth functions of time and the call's easting coordinate. The functional form of the quantile regression was

$$Q_\tau(y) = \beta_0 + f(day) + g(easting) + \beta_1(RL_{full} > bgrnd) + \beta_2(RL_{full} > bgrnd)RL_{full} \qquad \text{Eq. (6)}$$

where y (the response variable) was northing coordinate (UTMY, zone W) of the call, $Q_\tau(y)$ was the τ^{th} quantile of the northing coordinate, *f(day)* was a 6-degree polynomial function of day within the season, and *g(easting)* was a 6-degree polynomial function of the call's easting coordinate (UTMX, zones 6 and 7[4]), RL_{full} was the estimated received level of the airgun pulse at the call's location calculated using the "full array" method (see above), and *bgrnd* was background sound level at the time. The background sound level was the minimum SPL during a 16 h period centered on the time of interest, using average one-sec values from two DASARs at each site (A and F or G). The $RL_{full} > bgrnd$ term was a 0 – 1 indicator variable that took on the value 1 when RL_{full} was above *bgrnd,* and 0 otherwise. This model fitted no relationship between RL_{full} and $Q_\tau(y)$ when received levels were below background levels, and a linear relationship between RL_{full} and $Q_\tau(y)$ when received levels were above background levels. Primary interest was in whether $\beta_2 \neq 0$, implying some relationship between position of the call and received levels.

The *day* variable in the above model was coded as –1 for 30 Aug, 0 for 31 Aug, 1 for 1 Sep, 2 for 2 Sep, and so on. Seventeen quantile regressions were estimated for each site, one each for the quantiles τ=0.10, 0.15, …, 0.90. Estimation was performed using the R programming language (http:// www.r-project.org) augmented with the package *quantreg* (http://cran.r-project.org/src/contrib/Descriptions/quantreg.html). The *quantreg* package (version 4.10) performs quantile regression using a linear programming approach (Koenker and d'Orey 1987). To fit smooth functions of time and easting, *f(day)* and *g(easting)* were both represented by 6-degree polynomials. The degree of the polynomial to fit in both dimensions (i.e., 6) was chosen to match the effective degrees of freedom estimated by generalized cross-validation of a generalized additive model for the mean response (Gu and Wahba 1991; Gu and Ziang 2004; Wood 2004). After generalized cross-validation selected 6-degree polynomials, residuals were inspected for additional lack of fit; 6-degree polynomials provided an adequate fit to the data.

Because uncertainty in locations differed by several orders of magnitude among calls, a weighting factor derived from the size of the call's 90% confidence ellipse was used in all quantile regressions[5]. The weight used was the reciprocal of a representation of the ellipse's axis lengths. Representations of ellipse axes were computed as the average of the long axis of the ellipse and the radius of a circle with equivalent area. Weights used in the quantile regressions were

$$w = 2\big/(r_{long} + r_{circ}) \qquad \text{Eq. (7)}$$

where r_{long} was length of the ellipse's major axis, and r_{circ} was the radius of a circle that had equivalent area, i.e.,

$$r_{circ} = \sqrt{area/\pi}\ . \qquad \text{Eq. (8)}$$

These values up-weighted calls with precise locations (generally those within the boundaries of the DASAR array) relative to calls estimated with lower precision (generally those far from the array). The distribution of ellipse sizes contained a few calls with unrealistically small confidence ellipses given the estimated errors in individual bearings. To keep these few calls from dominating the results, we replaced $(r_{long} + r_{circ})$ by a small yet common value (500 meters) if $(r_{long} + r_{circ})$ was less than 500 meters.

Following estimation, quantiles of the northing coordinate of whale locations were predicted through time and space. To see variation of the call distribution through time, all 17 quantiles were estimated along

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[4] Site 1 was in UTM zone 5; sites 2, 3, and 4 were in UTM zone 6; and site 5 was in UTM zone 7.

[5] In other studies, it has been possible to estimate probability of including a location in the analysis, and to use this as a secondary weighting factor. It was not possible to reliably estimate probability of inclusion here.

the midpoint of the east-west extent of the data from each DASAR array. That is, the east-west midpoint of all locations within 10 km of a DASAR was computed, and then all 17 quantiles were estimated each day of the season using this midpoint as the easting coordinate in the estimated quantile regression equation.

Significance of the relationship between received levels and call locations was assessed by block permutation methods (Lahiri 2003; McDonald et al. 2008). Block permutation was used to allow for spatial and temporal correlation among call locations, and to correct significance levels for this correlation. Hierarchical cluster analysis was used to determine blocks of calls that were potentially correlated for use in the permutation process. During each step of hierarchical clustering, the two closest calls in time and space were amalgamated into the same cluster, and the spatial and temporal locations of all calls within the cluster were replaced by the centroid of (spatial and temporal) locations within the cluster. Amalgamation of clusters continued until the temporal correlation of vertical coordinates (y in above model) within three hours of one another equaled zero. Temporal correlation of y coordinates was measured by Moran's I (Moran 1950) statistic computed over clusters occurring within three hours of one another.

BWASP Trend Lines

This study aims to detect changes in bowhead whale distribution during the westward fall migration as a result of anthropogenic activities. To aid interpretation, it is useful to have information on the long-term location of the whale migration corridor. The **b**owhead **w**hale **a**erial **s**urvey **p**rogram (BWASP) has been conducting standardized aerial surveys of the Alaskan Beaufort Sea during late summer and autumn since 1982. From BWASP data collected during years that were similar to 2007 in terms of ice coverage, the whales' 10th, 50th (median), and 90th percentile location, across the longitude range 140º–152ºW, was estimated using a quantile regression model similar to the one described for call locations (above). Because migrating whales tend to be farther from shore in heavy ice years (Moore 2000; Treacy 2002; Treacy et al. 2006), and because fall 2007 saw very little ice coverage along the entire North Slope, BWASP data were restricted to the low ice years of 1998–2004. The quantile regression used to estimate locational trends in the BWASP data was of the form

$$Q_\tau(y) = \beta_0 + g(longitude)$$

where y was latitude (decimal degrees) of the BWASP sighting, $Q_\tau(y)$ was the τ^{th} quantile ($\tau = 0.1$, 0.5, and 0.9 here) of latitude, and *g(easting)* was a 7-degree B-spline polynomial function of the call's longitude (decimal degrees). Only non-repeat bowhead groups sighted on transect were used to fit the quantile regression. Seven degrees of freedom for the smooth function *g()* was chosen subjectively as the smallest degrees of freedom that followed the general trends of the BWASP data. Latitude and longitude coordinates, rather than UTM, were chosen for the estimation because of significant warping and inaccuracy of the large UTM grid covering all BWASP sightings.

Weather Information

Sea state has an effect on background sound levels and the detectability of whale calls. We monitored general trends in sea state over the duration of the field season by obtaining data from the National Climatic Data Center on wind speed (which is correlated with sea state) from two weather stations that are within our study area (see Fig. 8.3). The *Prudhoe Bay* station is located at 70.4° lat N, 148.517° long W, elevation 15 m (50 feet), and the *Barter Island* station is located at 70.133° lat N, 143.633° long W, elevation 36 m (119 feet). The shortest distance between the midpoint of each DASAR site (DASAR D) and the closest of the weather stations was 38 km, 70 km, 76 km, and 29 km (24 mi, 44 mi, 47 mi, and 18 mi) for sites 2, 3, 4, and 5, respectively.

RESULTS AND DISCUSSION

DASAR Performance and Call Counts

During the 2007 field season 35 DASARs were deployed, seven at each of five different sites (Fig. 8.3). Thirty-one DASARs were retrieved in Oct 2007, and another three were retrieved in Aug 2008. Of these, one DASAR did not provide any data (DASAR 1B), and one DASAR did not function during the first half of its deployment (DASAR 5D). Two DASARs rotated on the seafloor during their deployment (2C and 3C). All in all about 1578 useable DASAR-days of data were collected (including the two DASARs that rotated), amounting to about 37,860 hours of recordings. Over 540,000 call detections were obtained at all five deployment sites combined, representing over 168,000 individual calls that have been identified and classified. Call totals for all sites are shown in Table 8.4. DASARs at sites 1D, 1E, and 1F, which remained on the seafloor over the winter, continued recording until 17 Nov 2007, when their disk filled up. However, since the other DASARs at site 1 were retrieved on 12 Oct 2007, the call totals in Table 8.4 for DASARs 1D, 1E, and 1F do not include the period 13 Oct–17 Nov. Table 8.5 shows the number of days of operation for each DASAR and site over the entire field season. The 32 fully functional DASARs recorded for periods of 46–50 days, or 6.6–7.1 weeks. Figure 8.8 shows the mean number of calls detected per hour over the entire season, for each DASAR location. Call detection rates were highest for site 5, and decreased for each site westward (see also Table 8.4). Call detection rates at DASARs 5A, 5B, and 5C were particularly high, 1.7–200× those at any other DASAR. The highest hourly call detection rate (including all calls) was 462 calls per hour, obtained at site 5 on 13 Sep at 23:00. Figure 8.13 (introduced later) shows hourly rates of call detection at all sites over the entire field season, but only for calls within 10 km of the closest DASAR.

Figure 8.9 illustrates how the call detections were spread over the north-south extent of each site. Each array was made up of seven DASARs placed at the vertices of five "stacked" equilateral triangles (Fig. 8.3), with a spacing of 7 km (3.8 n.mi. or 4.3 mi) between adjacent DASARs. Each array was, therefore, about 5 km (2.7 n.mi. or 3.1 mi) wide and 21 km (11.3 n.mi. or 13 mi) long. Figure 8.9 shows that overall,

TABLE 8.4. Total numbers of calls detected at each DASAR location and all sites. The number of calls is smaller than the number of detections because each call can be detected by more than one DASAR. DASAR 1G was lost. A pound sign ($^{\#}$) indicates a DASAR that malfunctioned for some or all of its deployment.

DASAR location	Site 1	Site 2	Site 3	Site 4	Site 5
A	267	3505	22,878	26,552	54,149
B	0$^{\#}$	5649	23,480	28,225	50,877
C	5778	5610	23,528	27,195	48,028
D	8020	9880	20,473	13,462	7955$^{\#}$
E	7807	10,049	17,699	17,886	17,991
F	7753	11,158	11,155	17,136	5269
G	N.A.	7569	7106	14,060	5001
TOTALS:					
Detections	29,625	53,420	126,319	144,516	189,270
Calls	13,029	18,127	32,363	40,695	64,144

TABLE 8.5. Number of days of operation for each DASAR during the 2007 field season, and cumulative number of days per site. DASARs 1B and 5D malfunctioned for some or all of their deployment, and DASAR 1G was lost.

DASAR location	Site 1	Site 2	Site 3	Site 4	Site 5
A	49.111	49.269	46.371	48.983	49.460
B	0.000	49.192	46.444	49.057	49.512
C	49.239	49.074	46.837	49.106	49.551
D	49.218	48.971	46.772	49.169	20.863
E	49.199	48.846	46.706	49.235	49.841
F	49.176	48.753	46.329	49.281	49.756
G	0.000	48.617	46.551	49.350	49.819
Cumulative number of days:	245.942	342.722	326.011	344.181	318.801

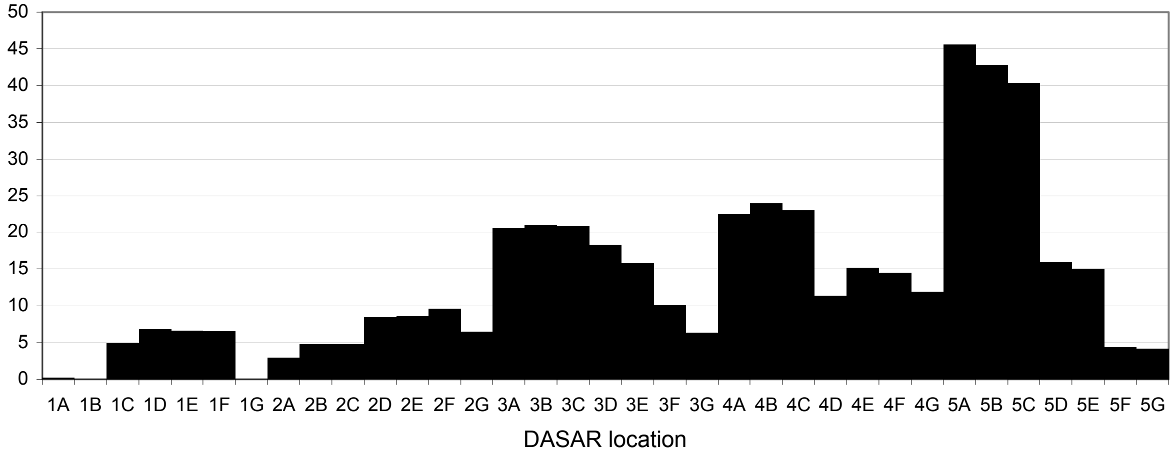

FIGURE 8.8. Mean number of call detections per hour over the entire deployment season for all DASAR locations. Note that DASAR 1G was never retrieved and DASARs 1B and 5D malfunctioned during some or all of their deployment.

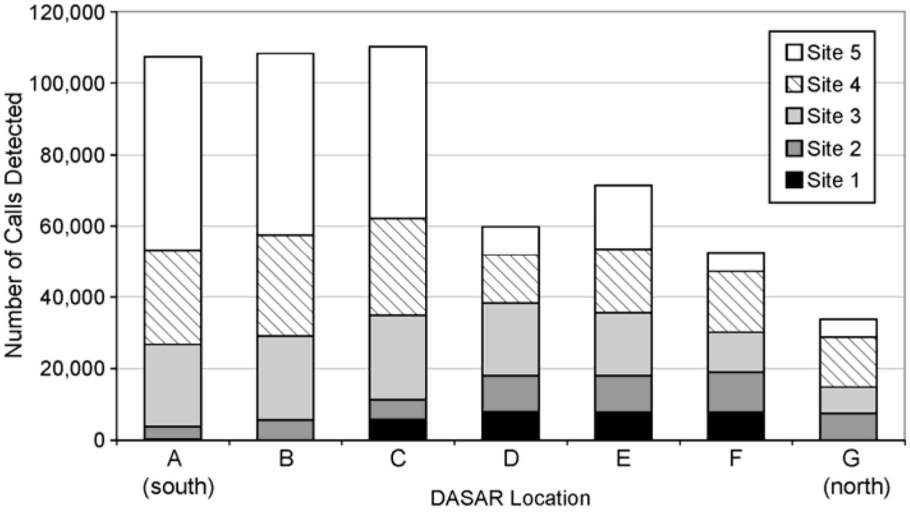

FIGURE 8.9. Numbers of call detections as a function of DASAR locations for sites 1–5. DASAR A was the farthest south at each site, and DASAR G the farthest north (see Fig. 8.3). Note that DASARs 1G, 1B, and 5D provided no or incomplete data sets.

DASARs in positions A, B, and C, at the southernmost end of the arrays, recorded the most calls. Sites 1 and 2, however, showed the opposite pattern with more calls recorded at the northern end of the array. The tendency for call detections to be progressively more common at the more offshore DASARs as whales progressed from east to west (Site 5 vs. Sites 4 and 3 vs. Sites 2 and 1; Fig. 8.9) may have been related to differences in water depths at the DASAR locations within the various sites. During migration, bowhead whales mainly travel over waters 20–50 m deep (Moore et al. 1989; Moore and Reeves 1993; Treacy 2002). Except for sites 3 and 4, water depths for DASARs at the five sites did not overlap by much (see Table 8.1). Site 1 (15–24 m or 48–78 feet) and site 2 (22–32 m or 72–104 feet) were at the lower end of the depth range generally favored by migrating bowhead whales, which could explain (for site 2) the larger number of calls detected at the northern end of the array. DASARs at Sites 3 and 4 were in the depth range 28–41 m (91–134 feet), and those at site 5 were at 39–54 m (127–176 feet), i.e., well within the depth range where most whales are seen during aerial surveys. The continental shelf at site 5 was narrower than at the other sites, with deeper waters closer to shore (see Fig. 8.3).

Location Estimates

Location estimates were obtained only if a call was detected by at least two DASARs. Location estimates are shown in Figure 8.10 for calls detected over the entire season at sites 2, 3, 4, and 5. At the time of this report any analyses for site 1—beyond the identification and tallying of whale calls—have not been completed. Figure 8.10A shows all positions obtained, regardless of the quality of the position estimate. A study similar to this one that took place in the Prudhoe Bay area (Richardson [ed.] 2008) showed that the detectability of calls decreased substantially beyond a distance of about 10 km. In addition, the precision of the call locations decreased at greater distances (see Fig. 8.7). Therefore, only the positions located within 10 km (5.4 n.mi. or 6.2 mi) of the closest DASAR were retained in some analyses, and these are shown in Figure 8.10B.

Figure 8.10C shows a map of BWASP sightings during the seven low-ice years 1998–2004, overlaid on a map of all location estimates from fall 2007 (also a low-ice year). The long-term trend in the whales' migration corridor, as measured by the 10th, 50th, and 90th percentiles, is shown in Fig. 8.10C. The percentiles, estimated from the BWASP quantile regression, delineate the corridor within which 80% of BWASP bowhead whale sightings have occurred in years of low ice cover.

Call Detection Rates as a Function of Seismic Activity

Calls Before and During Seismic Activity

Over the course of the study period, Shell conducted several seismic surveys in the Beaufort Sea (see Chapter 2). One of the goals of this study was to examine possible effects of anthropogenic sounds such as seismic pulses on measurable aspects of bowhead whale behavior, such as call detection rates (which we use as a proxy for calling rates) and whale movements. From 18 Sep to 3 Oct 2007 Shell conducted a seismic survey in an area between sites 3 and 4. Figure 8.11B shows the 4752 calls that were localized near sites 3 and 4 during this 15.3-day period. For comparison, Figure 8.11A shows the 32,308 calls that were localized near sites 3 and 4 during the 15.3-day period ***directly preceding*** the seismic survey. It also shows the location of the seismic survey, which came very close to some DASARs at site 4. The shortest distances between the center of the airgun array and the recorders were 900 m, 400 m, and 2.5 km (~2950 feet, 1310 feet, and 1.6 mi) for DASARs 4E, 4G, and 4C, respectively. DASARs at site 3 were located 10–24 km from seismic activities. Table 8.6 summarizes the distances between DASAR sites and Shell seismic activities.

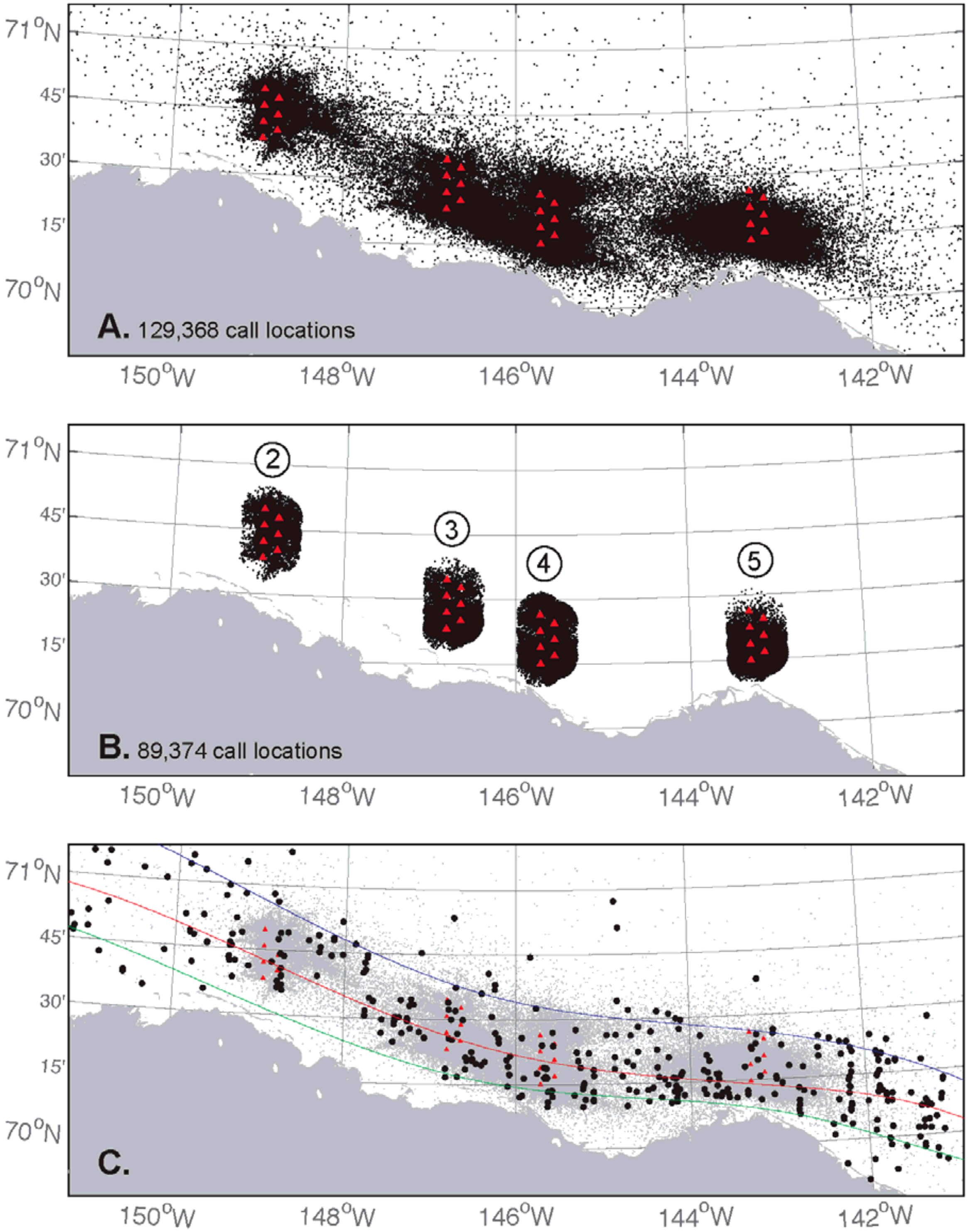

FIGURE 8.10. Call location estimates for sites 2, 3, 4, and 5. ***(A)*** All call locations obtained, irrespective of their precision. ***(B)*** Call locations within 10 km of the nearest DASAR. ***(C)*** BWASP sightings in the years 1998–2004 (black dots), as compared to all call locations obtained in this study in 2007 (gray dots). DASAR locations are shown as red triangles. The three lines show the 10th (green, bottom), 50th (red, middle), and 90th (blue, top) percentiles of distance from shore for whale sightings during BWASP surveys in 1998–2004.

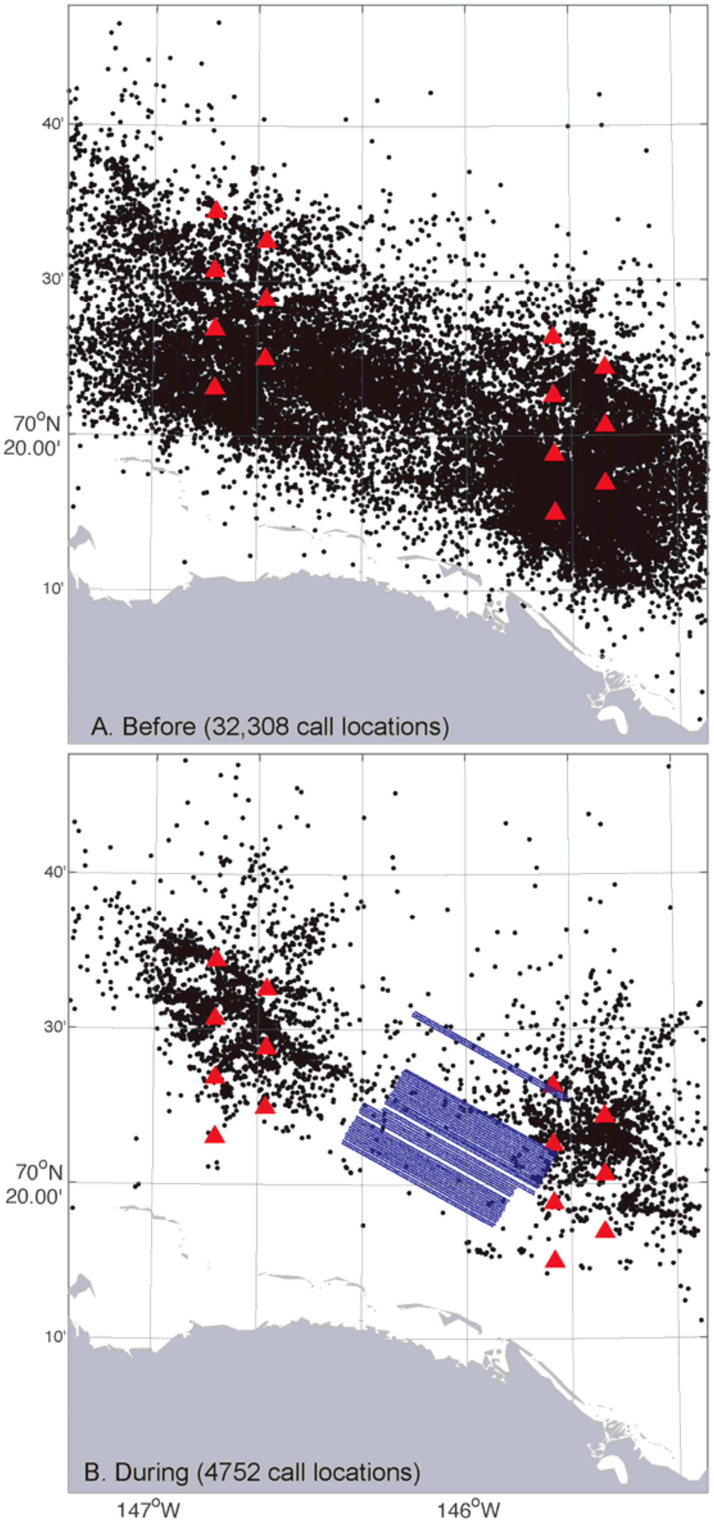

FIGURE 8.11. Whale call locations obtained before ***(A)*** and during ***(B)*** seismic operations (blue lines) that took place between sites 3 (left) and 4 (right). DASARs used to obtain these call locations are shown as red triangles. Seismic operations lasted from 18 Sept. to 3 Oct. 2007, a duration of 15.3 days. Plot ***(A)*** shows whale call locations obtained during the 15.3 days (3–18 Sept.) directly preceding the onset of seismic operations.

TABLE 8.6. Minimum, maximum, and mean distances between DASAR sites and Shell seismic activities, expressed in kilometers (km) and miles (mi).

		Site 1	Site 2	Site 3	Site 4	Site 5
Min	km	159	94	10	0.4	88
Max		194	130	47	35	122
Mean		177	112	29.1	17.5	105
Min	mi	99	59	6.3	0.22	55
Max		121	81	29	22	76
Mean		110	70	18	11	65

Visual inspection of Figure 8.11 shows that call detection rates dropped by about 85% between the two 15.3-day periods before and during seismic activities. The call detection rate at these two sites diminished from 2112 calls/d before seismic to 311 calls/d during seismic. However, this comparison does not take into account changes in wind speed, or in the number of passing bowhead whales, that may have occurred between the two periods. Wind is important because it elevates background sound levels and decreases the detectability of whale calls. Mean hourly wind speeds at the Prudhoe Bay and Barter Island weather stations over the field season are shown in Figure 8.12. It was on average about 50% higher during the period of seismic activity (Fig. 8.11B) than during the equivalent number of days preceding onset of seismic activity (Fig. 8.11A). Table 8.7 shows wind speed values for the corresponding periods. What this means is that some fraction of the drop in call detection rates during seismic activities can likely be explained by a decrease in call audibility due to higher background sound levels. It is also possible that there were progressive changes in the number of bowheads migrating through the area over the course of the period of study. That could also have contributed to the change in call detection rate at sites 3 and 4 in the before vs. during periods.

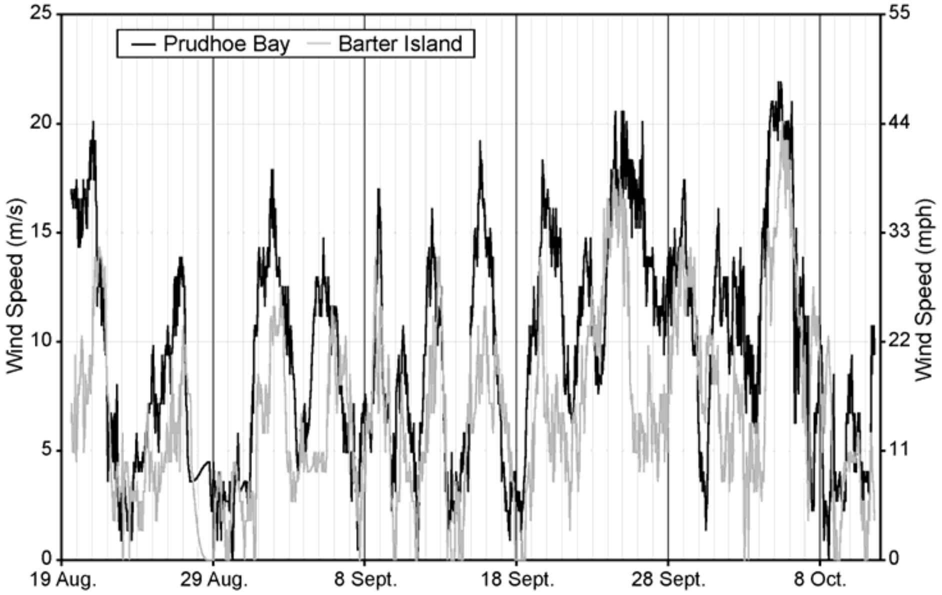

FIGURE 8.12. Mean hourly wind speed at weather stations located in Prudhoe Bay and on Barter Island (see Fig. 8.3), over the course of the 2007 field season. These weather stations are closest to sites 2 and 5, respectively.

TABLE 8.7. Mean wind speed, in m/s and mph, as recorded at the Prudhoe Bay and Barter Island weather stations, for the two 15.3-day periods shown in Figure 8.11, i.e., before (3–18 Sept.) and during (18 Sept.–3 Oct) seismic operations.

	Before seismic	During seismic	Change
Prudhoe Bay			
m/s	7.9	12.1	+53%
mph	17.6	27.0	
Barter Island			
m/s	5.6	8.2	+46%
mph	12.6	18.4	

Call Detection Rates while Controlling for Potentially Confounding Factors

To address these problems, we used the fact that call location data are available from sites 2 and 5 (more distant from the seismic operations) as well from sites 3 and 4 (near those operations), along with the fact that wind speed was fairly homogenous over the study area. The two weather stations, 186 km or 115 mi apart, showed similar trends of increasing and decreasing wind speeds over time (see Fig. 8.12). Therefore, sites 2 and 5, away from seismic activities, could serve as reference areas or "controls". If the increased average wind speed was solely responsible for the drop in call detection rates during the period of seismic activity, then we would expect to see the same drop at all sites. Similarly, contrasting the pattern at sites 3 and 4 with that at sites 2 and 5 can also control for any trend in overall numbers of passing whales that might have occurred across the study period.

Figure 8.13 shows the ***before***, ***during***, and ***after*** periods superimposed on plots of call detections per hour throughout the study period, from late August through early October, for all four sites. Only calls within 10 km of the closest DASAR were included. Note that the ***before*** period in this analysis is longer than that used in the call number comparison shown in Fig. 8.11. It began on 23 Aug., when DASAR monitoring had been initiated at all sites. These plots suggest that call detection rates at sites near seismic operations (3 and 4) were high in the before period, and relatively low—and similar—in the during and after periods. In contrast, sites far from seismic operations (2 and 5) do not show clear differences among the three periods, i.e., rates during the before period at sites 2 and 5 were not dramatically higher than during the other two periods. Plots summarizing the bootstrap distribution of average hourly counts at 12-hour intervals further confirm these patterns (Figure 8.14).

Poisson regression results indicate that the differences seen in these plots are statistically significant. In all 1000 bootstrap iterations, likelihood ratio tests comparing full and reduced models showed that the overall interaction between group (*near* and *far* from seismic) and period (***before***, ***during***, or ***after***) was highly significant ($p < 0.001$) for all inter-sample intervals and call locations, whether restricted to those within 10 km of the nearest DASAR or unrestricted with respect to distance. In other words, differences in call location rates among periods were not the same for sites near seismic operations compared to sites far from operations. However, the significant overall interaction effect does not indicate specifically where those differences occur. Linear contrasts on the interaction (Table 8.8) reveal the underlying details. These contrasts compare groups (*near* and *far*) across each set of two periods: ***before*** versus ***during***, ***before*** versus ***after***, and ***during*** versus ***after***. A significant test result indicates that the change in hourly number of call locations between the two periods differs for those sites near vs. far from seismic operations. As shown in Table 8.8, all comparisons of ***before*** versus ***during*** were significant ($p < 0.001$). Comparisons of ***before***

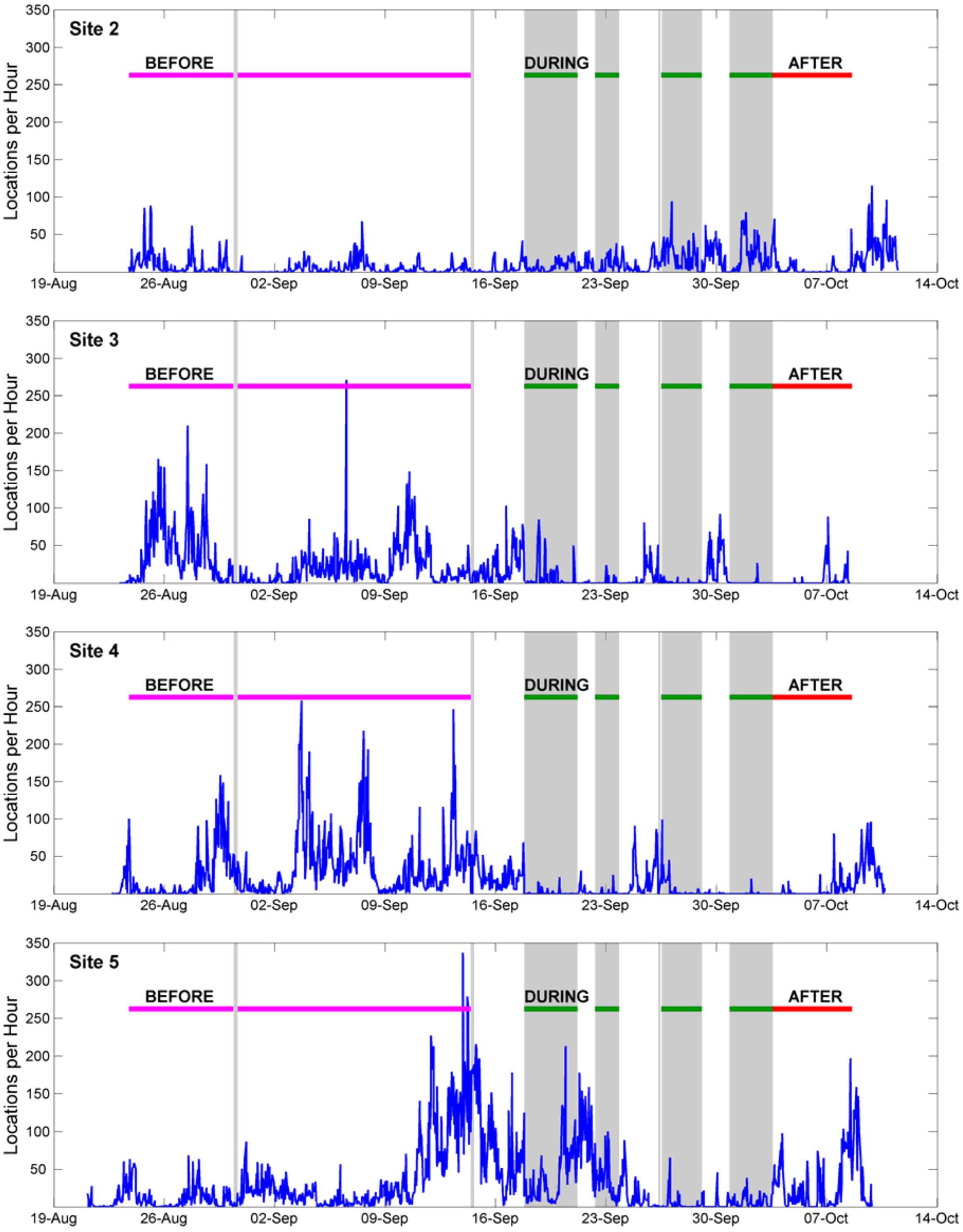

FIGURE 8.13. Hourly call location rate at sites 2, 3, 4, and 5 over the entire season (blue line), as a function of seismic operations (gray shading). Only call locations within 10 km of the nearest DASAR were included. The 3 periods ***before***, ***during***, and ***after*** seismic are shown with pink, green, and red lines, respectively. The ***before*** period did not include a brief interval of seismic testing on 30 Aug. The ***during*** period included the four longest intervals of continuous seismic operations, and did not include the intervening intervals when airguns were not firing.

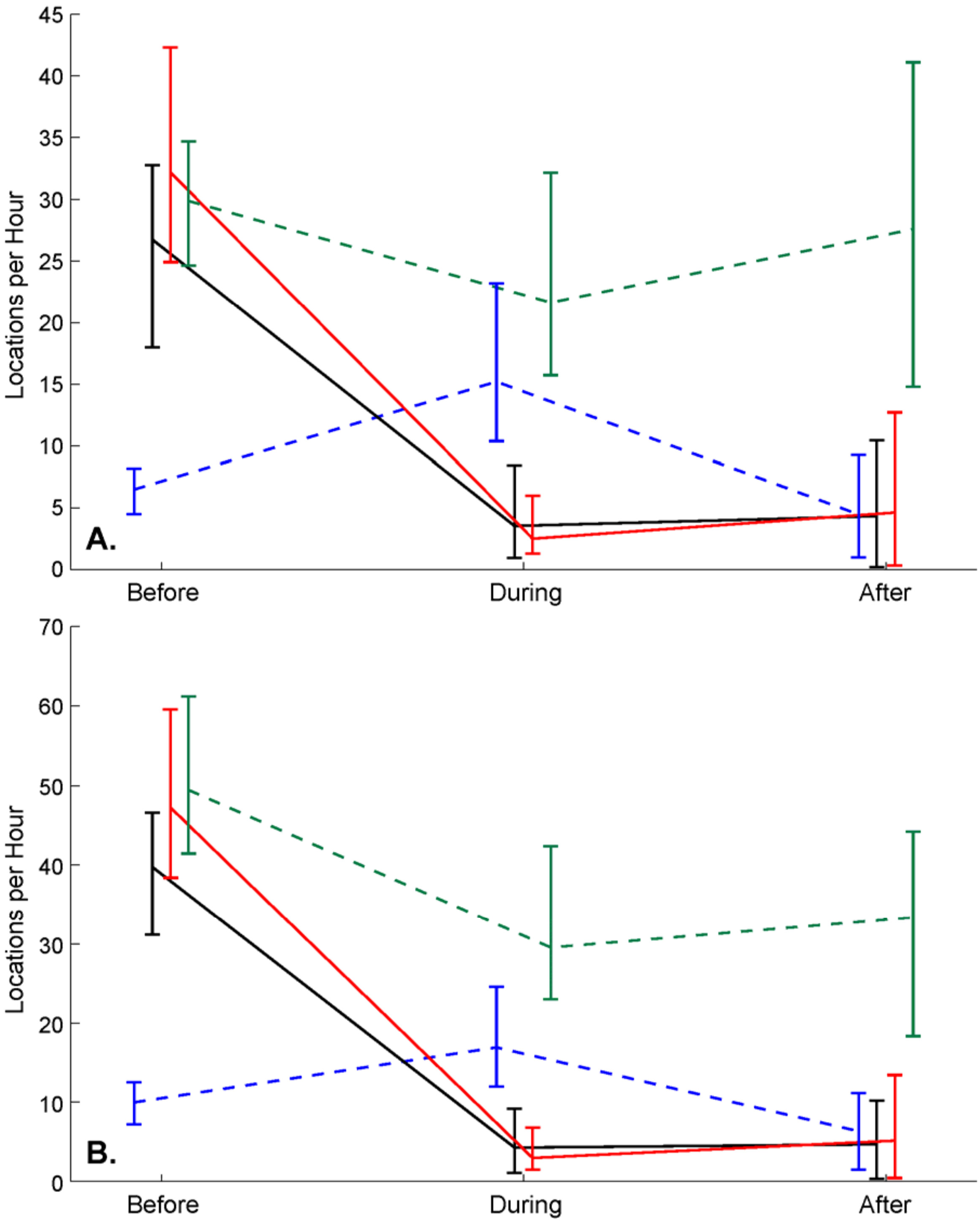

FIGURE 8.14. Average hourly call counts at 12-hour intervals ***before***, ***during***, and ***after*** seismic operations at sites *near* operations (solid lines, site 3: black, site 4: red) and sites *far* from operations (dashed lines, site 2: blue, site 5: green). Means and 95% confidence limits (based on percentile method) of 1000 bootstrap samples. ***(A)*** Using only calls with a position estimate within 10 km of the nearest DASAR. ***(B)*** Using all calls.

TABLE 8.8. Bootstrap results for Poisson regression showing the proportion of 1000 *p*-values > 0.05. Linear contrasts compare the two groups of sites (*near* and *far* from seismic operations) across each pair of periods. Results are shown while using only call locations within 10 km of the closest DASAR at each site, or using all call locations.

Inter-sample interval	Location Set	***before*** vs. ***during***	***before*** vs. ***after***	***during*** vs. ***after***
6 hrs	Locations within 10 km	0	0	0.093
	All locations	0	0	0.089
12 hrs	Locations within 10 km	0	0	0.137
	All locations	0	0	0.087
18 hrs	Locations within 10 km	0	0	0.398
	All locations	0	0	0.390
24 hrs	Locations within 10 km[1]	0	0.043	0.288
	All locations[2]	0	0.021	0.264

[1] Poisson regression failed to converge in 14 of 1000 replicates.

[2] Poisson regression failed to converge in 10 of 1000 replicates.

versus ***after*** were also significant at $\alpha = 0.05$. However, all comparisons of ***during*** versus ***after*** were non-significant. Furthermore, it is clear from this last set of comparisons that as inter-sample interval increased from 6 to 24 hours, *p*-values generally increased also (i.e., differences became less pronounced). This result was the consequence of decreasing sample sizes with longer intervals, particularly within the ***after*** period. Nonetheless, the basic conclusions drawn from these results are independent of inter-sample intervals: there are significant interactions between ***before*** and both ***during*** and ***after***, and no significant interaction between ***during*** and ***after***. These test results are consistent with Figures 8.13 and 8.14 in showing high hourly call location rates at both sites 3 and 4 before seismic operations and substantially lower rates during and after operations, contrasting significantly with relatively small changes between periods at sites 2 and 5.

Our analysis shows a clear and statistically significant drop in call detection rates with the onset of seismic activities. This decrease could be caused by a reduction in calling rate (per whale), or by avoidance of the area by some whales in response to the seismic program (i.e., deflection), or a combination of the two. However, distinguishing between these hypotheses cannot easily be done from acoustic data alone.

A few previous studies have examined the *effects of seismic survey activities on call detection rates* of bowhead whales. Greene et al. (1998; 1999) used autonomous seafloor acoustic recorders to monitor bowhead call detection rates during the use of airguns in the Alaskan Beaufort Sea in late summer/early autumn. Call detection rates (per hour) at the recorders closest to the airguns were significantly lower at times with pulses than without, and concurrent aerial surveys showed that most bowheads were displaced from the area near the operating airguns. Richardson et al. (1986) used sonobuoys and aircraft-based observations to study the reactions of bowhead whales to seismic exploration in the Canadian Beaufort Sea during summer. They found that average call detection rates (per whale) were slightly less for bowheads exposed to seismic pulses compared to undisturbed bowheads.

Regarding the *effects of seismic survey activities on bowhead whale movements*, studies in the 1980s showed that bowhead whales within a few kilometers of seismic activities generally moved away from the area (Richardson et al. 1986; Koski and Johnson 1987; Ljungblad et al. 1988). Based on data collected in

1996–1998, Miller et al. (1999) and Richardson et al. (1999) showed that most autumn-migrating bowhead whales apparently avoided seismic vessels operating in the Alaskan Beaufort Sea by 20–30 km.

Our findings are generally consistent with these earlier studies, and particularly with the Alaskan study of Greene et al. (1998; 1999), i.e., seismic surveys lead to a significant decrease in the call detection rates of bowhead whales. The rapid increase in call detection rates at sites 3 and 4 during breaks in seismic activities (Fig. 8.13) lends support to the hypothesis that at least some whales remained in the area during periods with seismic operations but altered their calling patterns in response to airgun sounds. In addition, after the onset of seismic operations we did not see a "trail" of calls at sites 3 and 4, at increasing distances from the seismic vessel, as would be the case if the whales left the area while continuing to call. Similarly, soon after the end of seismic operations calls started appearing close to the seismic operations area, so the whales could not have been too far away. The aerial surveys that were part of the present study (Chapter 7) showed high sighting rates near seismic operations, and these sightings consisted primarily of whales that appeared to be feeding, as opposed to migrating. Miller et al. (2005) have shown that bowhead whales are more tolerant of seismic operations when an attractant such as food is present. The aerial surveys also showed that rather than being displaced by seismic activities bowhead whales appeared to aggregate in the vicinity of seismic operations, while showing mild avoidance to the seismic operations. Again, the cause of this behavior seems to have been the presence of feeding patches (Chapter 7).

There two other factors in addition to seismic surveys that could contribute to a decrease in call detection rates. **Weather** (sea state) has an important effect on the audibility of whale calls, since an increase in background levels leads to a lower signal to noise (S/N) ratio. This would be a considerable problem if measurements had only been made at one site (for example site 3 or 4). However, because both "near" and "far away" sites were considered, and fluctuations in wind speed were fairly consistent across the study area (see Fig. 8.12), the far sites served as controls for the near sites. **Masking** of calls by seismic noise is another issue, and it is possible that a small fraction of calls were masked by concurrent seismic pulses. However, seismic pulses are generally of shorter duration (generally < 0.5 s) than most bowhead calls (generally 0.5–5 s, median ~1.6 s). Also, their clocklike regularity makes them relatively easy to find and to distinguish from whale calls. Bowheads and other cetaceans are known to continue calling when seismic survey sounds are present, though calling frequency may change, and the calls are readily detectable between seismic pulses (Richardson et al. 1986, Greene et al. 1999). Except in cases where seismic pulse duration is extended by strong reverberation effects, seismic pulses would not mask more than a small fraction of the whale calls.

Seismic Pulse Characteristics

During the 2007 field season thousands of airgun pulses were recorded by the DASARs. The origin of these pulses before the onset of Shell seismic operations on 18 Sep was not investigated in detail, but many of these pulses originated in the Canadian Beaufort, to the E or ENE of our DASAR arrays. The source of these pulses was likely a deep-water seismic survey carried out by GXT. The pulses were detected and analyzed automatically for three parameters, the peak (instantaneous maximum) of the absolute sound pressure, the pulse duration, and the sound exposure level (SEL) over the duration of the pulse. Results of these analyses are summarized in Table 8.9 for DASARs at both northern and southern ends of sites 2, 3, 4, and 5. This analysis is not limited to the seismic pulses received during Shell operations, but includes all pulses detected by the DASARs. Note that DASARs overloaded when the instantaneous peak pressure exceeded 153 dB re 1 μPa so some of the maximum values are not true maxima.

TABLE 8.9. Summary of seismic pulse analyses for a selection of DASARs at sites 2–5. The minimum, median, and maximum values are given for sound exposure levels (SEL) of seismic pulses, the instantaneous peak pressure of seismic pulses, and background SPLs. n is the sample size, for both seismic pulses and background samples.

	n	Pulse SEL (dB re 1 uPa^2 · s)			Pulse Instantaneous Peak (dB re 1 uPa)			Background SPL (dB re 1 uPa)		
Site	pulse / backgr	Min	Median	Max	Min	Median	Max	Min	Median	Max
2A	365 / 7154	78.1	105.8	125.9	86.7	112.9	144.0	60.0	86.8	98.2
3A	556 / 6900	63.5	125.9	148.2	93.1	125.3	153.7	63.2	87.5	112.9
4A	481 / 7063	76.0	115.4	151.2	95.3	127.4	153.2	62.6	88.8	126.8
5A	677 / 6921	82.2	110.3	126.3	92.0	122.0	140.4	63.0	84.2	106.5
2G	505 / 7154	80.7	103.6	136.5	89.9	113.1	150.4	60.3	85.1	101.6
3F	596 / 6763	92.6	113.3	151.3	104.0	125.2	153.4	67.4	90.3	122.3
4F	551 / 7120	82.8	112.9	151.3	94.4	125.5	153.1	67.0	89.9	130.5
5F	396 / 3932	85.5	110.1	129.7	95.3	120.6	142.6	65.5	84.3	110.8
5G	705 / 6996	86.7	112.6	137.5	96.8	124.3	147.6	65.2	87.7	113.1

Figures 8.15 and 8.16 show time-series of received levels of sounds (peak and SEL) from seismic pulses over the course of the field season, from selected DASARs at sites 2, 3, 4, and 5. Ambient (non-pulsive) levels are also shown. Ambient levels are generally determined by wind speed and sea state, which explains why they showed similar patterns across our entire study area (sites 2 and 5 were separated by about 215 km or 134 mi). However, closer to seismic operations ambient levels can increase due to contributions by long-term reverberation from the airgun pulses, in addition to the sounds produced by the seismic vessel itself. This is visible in Fig. 8.15 and 8.16 by comparing the background SPL line for sites close to vs. farther from seismic operations (sites 3 and 4 vs. 2 and 5, respectively). For example, the jagged background lines for DASARs 3F and 4F starting on 18 Sep (Fig. 8.15 and 8.16) correspond to the seismic ship's consecutive passes during data acquisition (see Fig. 8.11). These heightened background levels are not visible in the records of DASAR 2G (107–130 km or 66–81 mi away) or 5G (88–115 km or 55–71 mi away).

We investigated the relationships between peak value, SPL, and SEL for the seismic pulses recorded by at least one DASAR at each site. The duration of a seismic pulse generally increased with distance from its source because of propagation effects. Therefore, the relationship between peak, SPL, and SEL values will also change with distance from the source, so we report results for a site close to seismic operations (site 4, ~27 km away) and a site far from seismic operations (site 1, ~173 km away). All overloaded (distorted) pulses were eliminated from this analysis: we conservatively eliminated all pulses with instantaneous peak values above 152 dB re 1 μPa; saturation was manifest at 153.2 dB re 1 μPa.

- Peak and SPL: instantaneous peak values were on average 11.1 ± 1.7 dB (mean ± S.D.) higher than SPL values at site 4 and 13.4 ± 2.5 dB higher than SPL values at site 1 (sample sizes 22,895 and 90, respectively). The maximum difference was 26 dB and 20 dB for sites 4 and 1, respectively. Since the duration of a pulse generally increases with distance from the source one would expect a larger difference between peak and SPL values at the greater distance, which is what our data show.

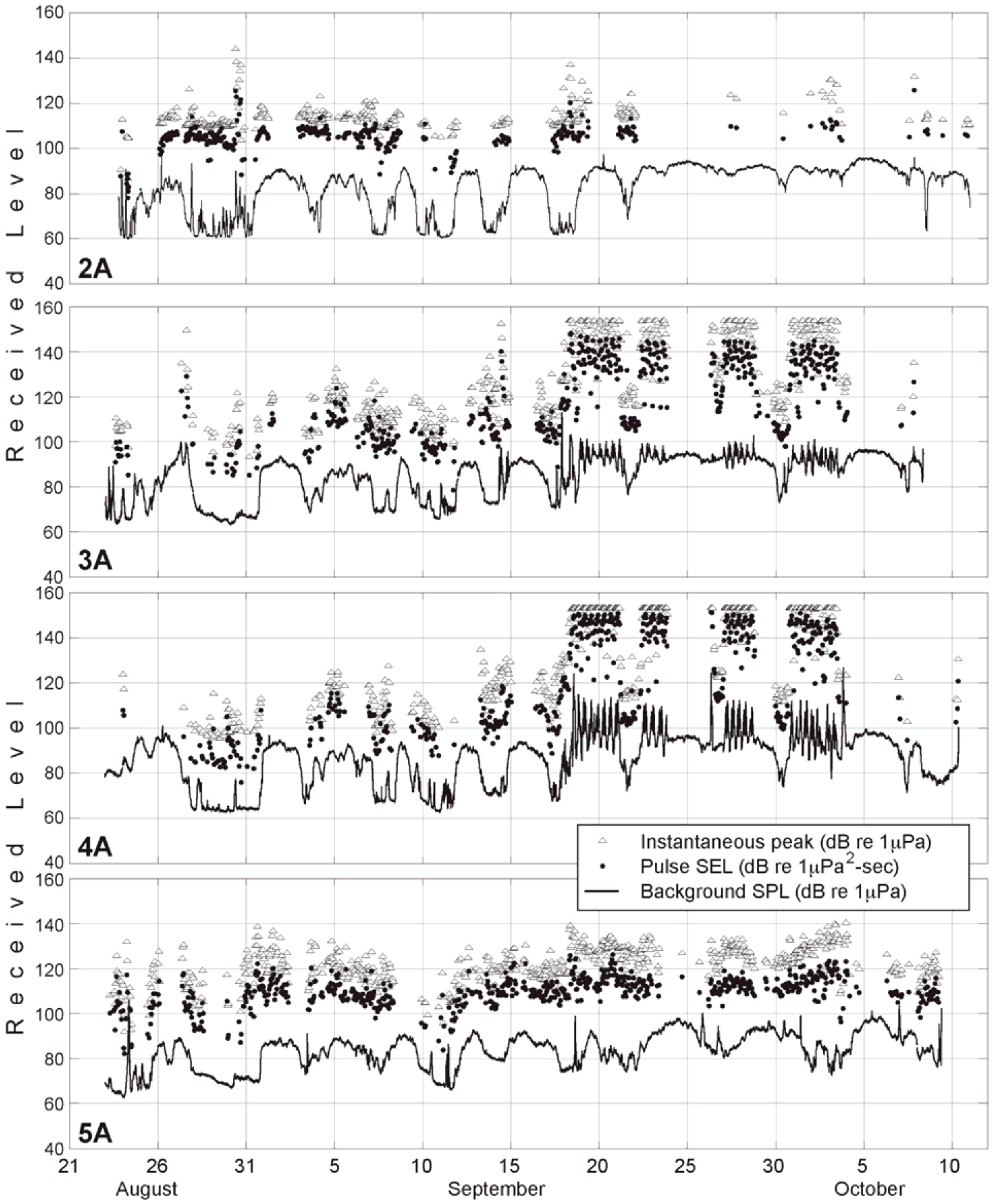

FIGURE 8.15. Received levels of sound from seismic pulses at sites 2A, 3A, 4A, and 5A (southernmost DASAR at each site). The maximum value obtained each hour is shown for the instantaneous peak (in dB re 1 μPa) and the pulse sound exposure level (in dB re 1μPa^2·s). Peak levels above 153 dB re 1 μPa are clipped. The continuous line shows ambient sound pressure levels.

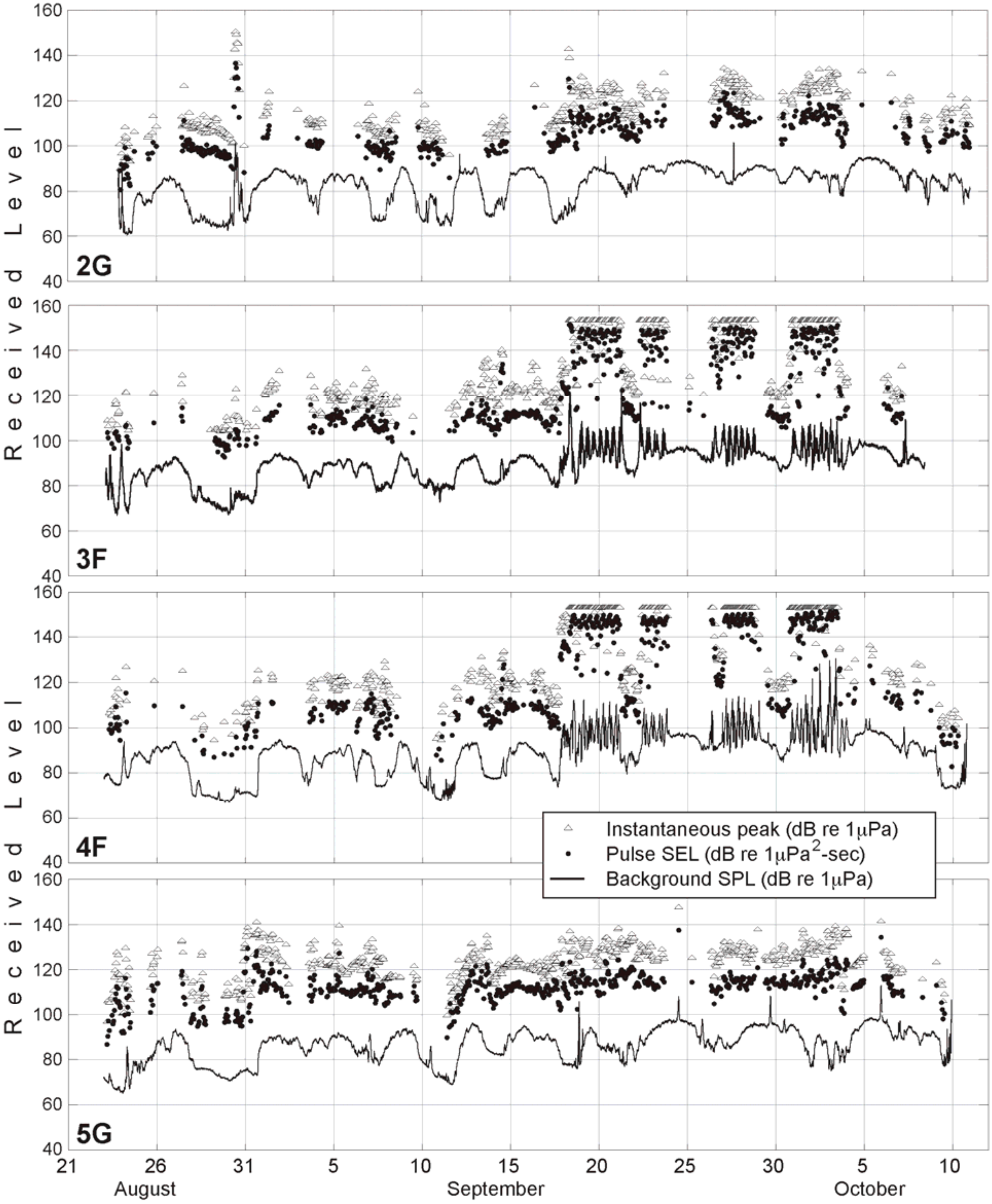

FIGURE 8.16. Received levels of sound from seismic pulses at sites 2G, 3F, 4F, and 5G (G is the northernmost DASAR at each site). The maximum value obtained each hour is shown for the instantaneous peak (in dB re 1 μPa) and the pulse sound exposure level (in dB re 1μPa^2·s). Peak levels above 153 dB re 1 μPa are clipped. The continuous line shows ambient sound pressure levels.

- SPL and SEL: mean SPL was 0.1 ± 2.1 dB higher than SEL at site 4, and 1.8 ± 3.8 dB lower than SEL at site 1. At all sites combined the differences ranged from about –9 dB (i.e., SPL lower than SEL) to +24 dB (i.e., SPL higher than SEL). Note that SPL and SEL are dimensionally different, with units of dB re 1 μPa and dB re 1 $\mu Pa^2 \cdot s$, respectively. Again, since pulse duration generally increased with distance from the source, one would expect SPL values to become relatively smaller, compared to SEL values (different units), with increasing distance from the source. The same trends were seen in our data sets.

Airgun pulses that were detected before the onset of seismic operations by the *Gilavar* (18 Sept.) likely originated in the Canadian Beaufort Sea. This is supported by the fact that received levels (RLs) of these pulses, as shown in Fig. 8.15 and 8.16, tended to be higher at the easternmost sites (i.e., site 5) than at the westernmost sites (i.e., site 2). These distant airgun pulses were detected mainly when background levels were low, with gaps in detection when background levels were higher. It is also noteworthy that at DASAR 5G RLs for pulses from the Canadian Beaufort are about the same as RLs from seismic operations by the *Gilavar*. This is in contrast to site 2G, where RLs from seismic operations by the *Gilavar* are higher. As expected, RLs for airgun pulses from the *Gilavar* were much higher at sites 3 and 4 than at sites 2 and 5.

Received SPLs from seismic pulses, as recorded by at least one DASAR at each of the 5 sites, were analyzed during a one-hour period (10:30–11:30) on 18 Sep 2007, when the *Gilavar* conducted seismic operations at a location between sites 3 and 4, using its full array (24 guns). We combined this information with the position of the airgun array and fit a propagation model to the received levels obtained from the DASARs. The model was compared to that obtained by JASCO Research Inc. during their sound source verification (SSV). The data are summarized in Figure 8.17 and show good agreement between the two data sets within the range of distances over which the models were calculated. The intercepts for the two equations are actually quite different (278.1 vs. 245.2) and so are the spreading loss terms (28.7 vs. 19.9). This indicates that received level extrapolations should only be made over distances within the range of measurements (i.e., 25–173 km for the DASAR-based model). Table 8.10 compares calculated received levels at a range of distances, using either the DASAR-derived formula or the SSV-derived formula. Again, there is good agreement for distances up to at least 80 km.

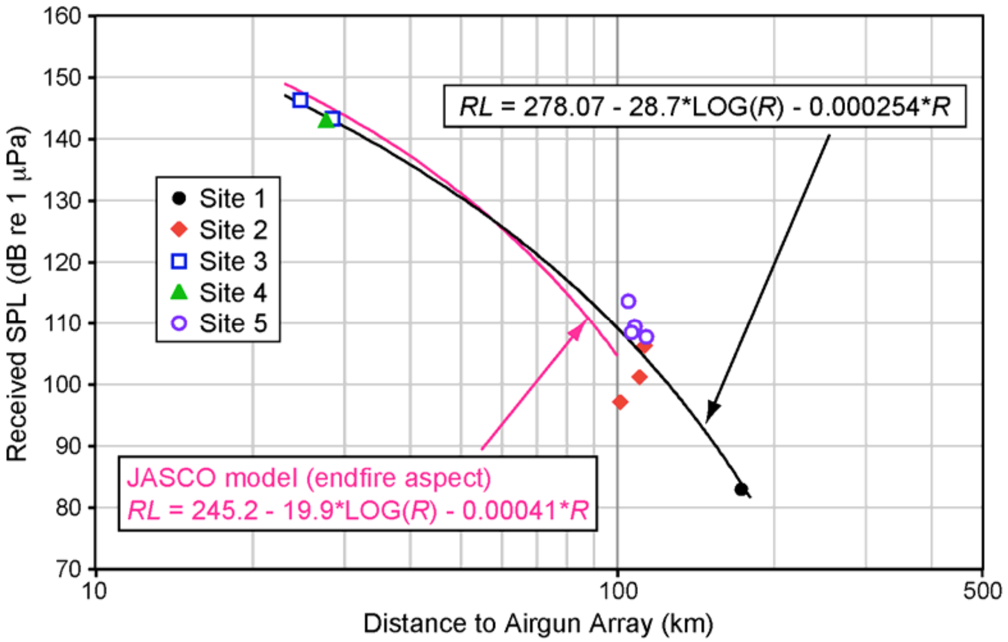

FIGURE 8.17. Received SPLs of seismic pulses at one or more DASARs from all five sites. Each symbol represents a mean received level from one DASAR, except for site 3. Here the data set was split into two groups. A logarithmic propagation model was fitted to the data; the resulting equation is shown in the plot. The endfire equation fitted by JASCO during SSV (see Table 8.3) is also shown for comparison.

TABLE 8.10. Comparison of calculated received SPLs (in dB re 1µPa), using either the DASAR-based propagation equation or the JASCO SSV equation (*Gilavar*, 24 guns, far field equation in Table 8.3), at a range of distances.

	25 km	**30 km**	**40 km**	**50 km**	**60 km**	**80 km**	**100 km**
DASAR	145.5	142.0	135.8	130.5	125.7	117.1	109.2
JASCO	147.4	143.8	137.2	131.2	125.5	114.8	104.7
Difference (dB):	1.9	1.8	1.4	0.7	0.2	2.2	4.5

Received Levels of Seismic Pulses at Whale Call Locations

Table 8.11 summarizes estimated received levels of *Gilavar* and *Henry Christoffersen* airgun sound at whale call locations for each site, each data set (all calls or only those within 10 km), and using the “concurrent” and “full array” calculation methods. Figures 8.18 and 8.19 show histograms of received levels for each site, using only calls whose locations were within 10 km of the closest DASAR at a site. RLs were calculated with the “concurrent” method in Figure 8.18 and with the “full array” method in Figure 8.19.

TABLE 8.11. Summary statistics for estimated received levels of *Gilavar* and *Henry Christoffersen* airgun pulses at whale call locations by site, method (*concurrent* seismic state, or assuming the *full array* was firing), and data set (all call locations, or only those within 10 km of the nearest DASAR at each site).

Site	Calculation method	Data set	Mean	Median	% > 120 dB	% > 140 dB
Sites far from seismic operations						
2	“Concurrent”	Only calls within 10 km	98.0	98.4	0.0	0.0
		All call locations	98.5	98.7	0.3	0.0
	“Full array”	Only calls within 10 km	100.9	100.8	1.7	0.0
		All call locations	101.5	101.6	2.1	0.0
5	“Concurrent”	Only calls within 10 km	98.4	100.3	0.1	0.0
		All call locations	98.2	99.4	1.3	0.2
	“Full array”	Only calls within 10 km	99.7	100.4	0.6	0.0
		All call locations	99.9	100.0	2.2	0.5
Sites near seismic operations						
3	“Concurrent”	Only calls within 10 km	114.2	109.8	34.1	2.9
		All call locations	112.5	109.3	31.8	3.0
	“Full array”	Only calls within 10 km	134.6	134.0	92.8	19.6
		All call locations	128.3	132.1	79.4	18.8
4	“Concurrent”	Only calls within 10 km	114.8	112.5	25.7	5.6
		All call locations	115.6	113.5	29.8	5.7
	“Full array”	Only calls within 10 km	138.4	138.0	94.0	44.0
		All call locations	139.0	138.8	93.6	46.4

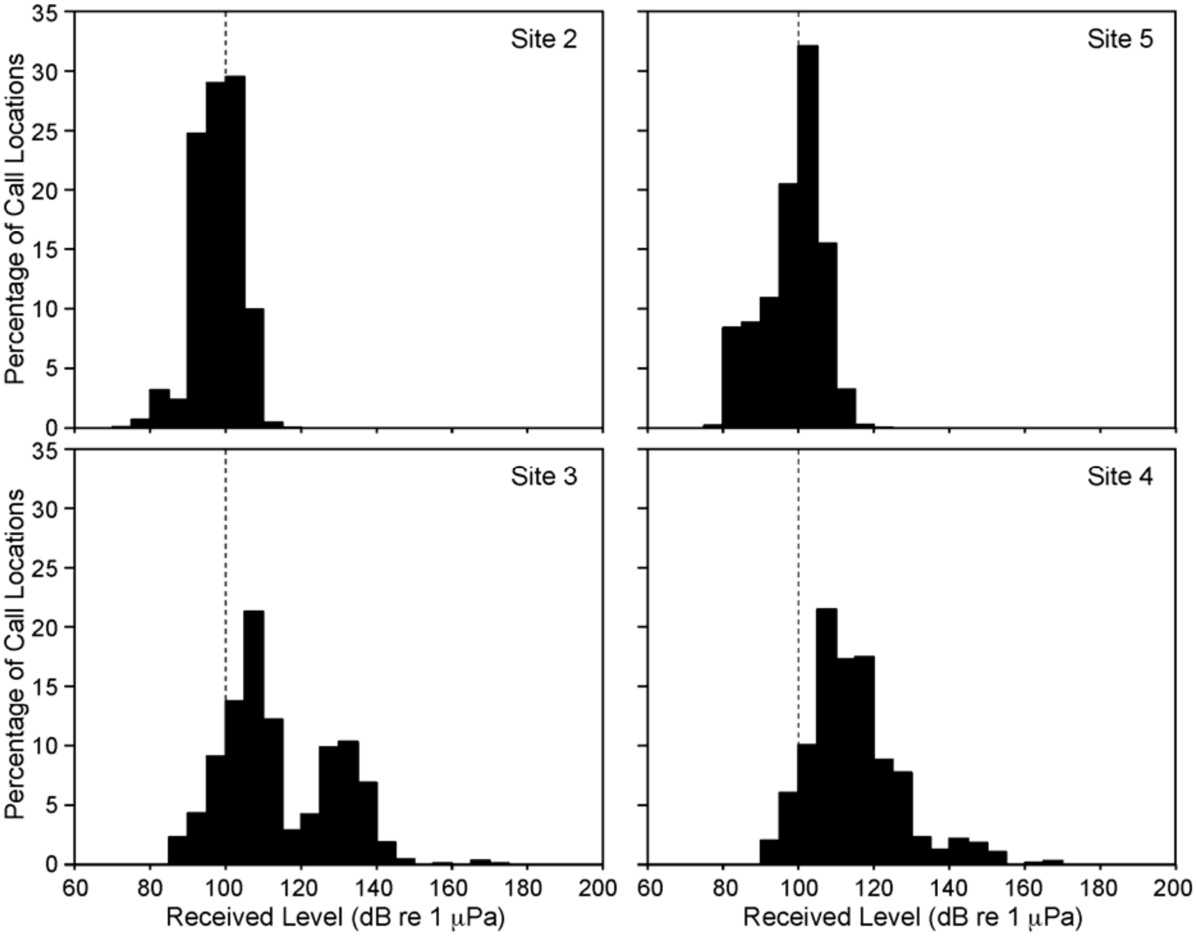

Figure 8.18. Histograms of estimated received levels of seismic pulses from *Gilavar* and *Henry Christoffersen* at sites far from Shell's seismic operations (sites 2 and 5, top) and sites close to seismic operations (sites 3 and 4, bottom). Received levels were calculated based on seismic operations concurrent with the call. Only whale calls with locations within 10 km of the nearest DASAR were used at each site. Dashed line at 100 dB is a reference to facilitate comparisons.

For call locations at sites 2 and 5, far from seismic operations, mean RLs of seismic pulse sounds were estimated as ~100 dB re 1 μPa. Less than 3% of calls near those sites had estimated RLs that exceeded 120 dB, and less than 1% of calls had levels exceeding 140 dB (in most cases, no calls were exposed to levels above 140 dB, see Table 8.11). Sites 2 and 5 were west and east of Shell's seismic activities, respectively, but their received levels were similar, and the choice of calculation method ("concurrent" vs. "full array") led to increases in mean RLs of less than 3 dB (Table 8.11).

In contrast, estimated RLs at sites 3 and 4, near seismic operations, were higher (Table 8.11, Fig. 8.18, 8.19), as expected. At these sites the choice of calculation method, "concurrent" or "full array", led to large differences in estimated received levels, 15–25 dB. Under the "concurrent" method, mean RLs were ~115 dB re 1 μPa, with ~30% exceeding 120 dB and 3–5% exceeding 140 dB. Under the "full array" assumption, mean RLs were ~130–140 dB, with as much as 90% of RLs exceeding 120 dB and 20–45% of values exceeding 140 dB (Table 8.11).

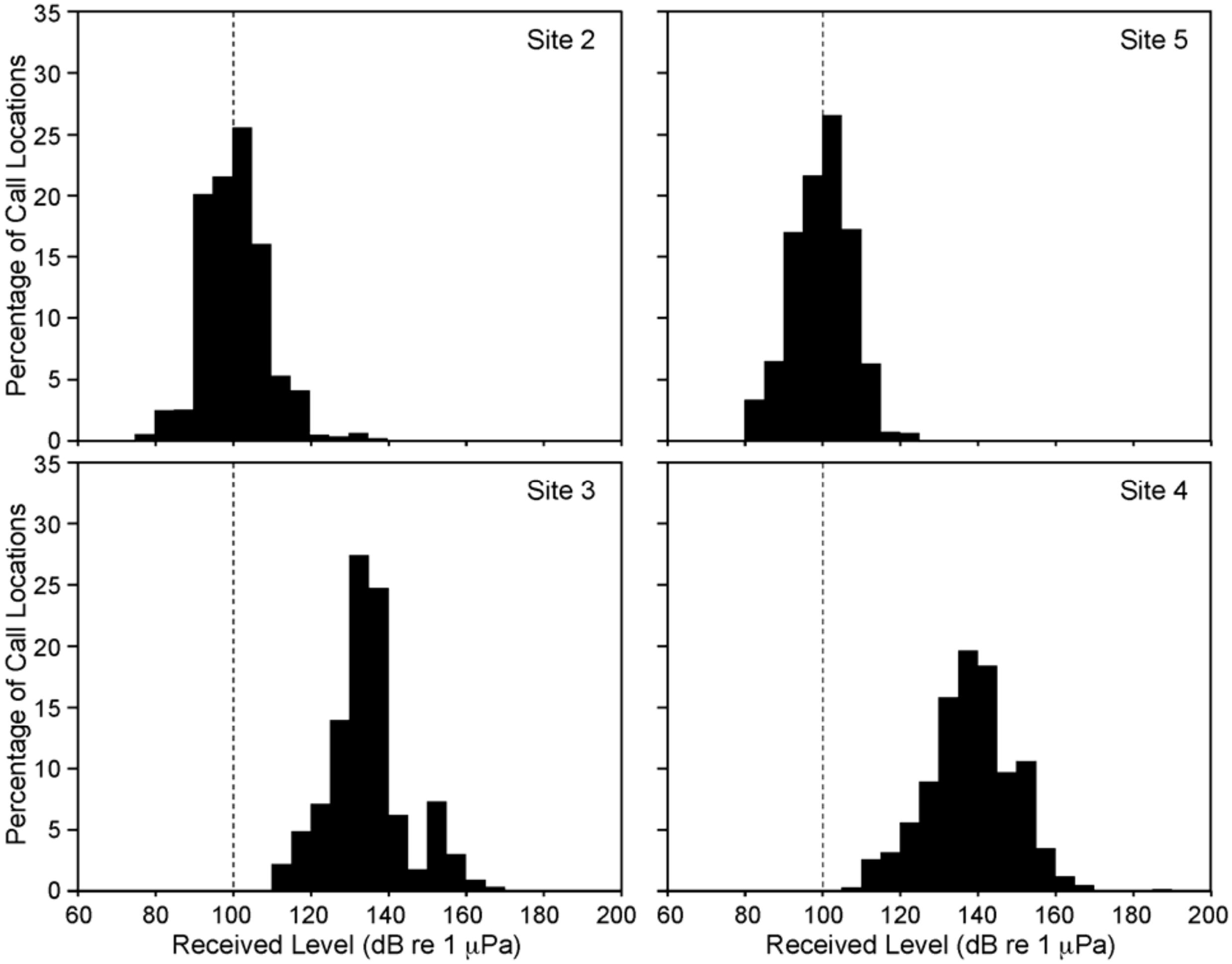

Figure 8.19. Histograms of estimated received levels of seismic pulses from *Gilavar* and *Henry Christoffersen* at sites far from Shell's seismic operations (sites 2 and 5, top) and sites close to seismic operations (sites 3 and 4, bottom). Received levels were calculated assuming all seismic operations were taking place using the full array. Only whale calls with locations within 10 km of the nearest DASAR were used at each site. Dashed line at 100 dB is a reference to facilitate comparisons.

A received sound pressure level (at the animal) of 180 dB re 1 μPa is the "do-not-exceed" limit for cetaceans for impulsive sounds, as set by NMFS (NMFS 2000). It is therefore of interest to calculate how many of our call locations had RLs exceeding 180 dB. When we limited the analysis to call locations that were within 10 km of the nearest DASAR our sample size was 89,374 calls (Fig. 8.10). With the "concurrent" method (in which we use the measured source level for the airguns said to be in use) none of these call locations had calculated RLs exceeding 180 dB. With the "full array" method (in which every airgun pulse was assumed to have come from the full array) one call location had an estimated RL in the range 185–190 dB. These results suggest that mitigation measures, as implemented using Marine Mammal Observers, are effective at preventing bowhead whales from being subjected to RLs of 180 dB or more. However, this conclusion can only be applied to calling animals; individuals that are not calling or that stopped calling because of the seismic activities (see section *Call Detection Rates while Controlling for Potentially Confounding Factors*) are not included in this assessment.

In general, there was little difference in estimated RLs whether analysis was restricted to calls from within 10 km of the nearest DASAR or analysis was unrestricted and all calls were used (Table 8.11). The greatest differences occurred at site 3, where the inclusion of calls beyond 10 km resulted in somewhat lower average received levels.

Results from an analysis of variance based on block permutation showed that among-site differences in mean estimated RLs were, not surprisingly, highly significant. All overall *F*-tests as well as all associated *t*-tests of the contrasts between sites near and far from seismic operations had *p*-values < 0.001. These results held for all conditions considered: (1) concurrent assumption, call locations within 10 km of the nearest DASAR; (2) concurrent, all call locations; (3) full array assumption, ≤10 km; and, (4) full array, all locations.

Quantile Regression of Whale Call Locations

Figure 8.20 shows estimated quantiles of the onshore-offshore distribution of bowhead calls within 10 km of the nearest DASAR. Quantiles represent times when received sound levels of airgun pulses from *Gilavar* and *Henry Christoffersen* were either absent or *below* background at a representative east-west location in the middle of each site, for sites 2–5 over the course of the field season.

In general, all the curves in Figure 8.20 suffer from low samples sizes at various times of the season, including (for most sites) the beginning and end of the season, but also at various other times. In particular, the lines estimated for the latter third of the season (approximately, depending on site) were based on very few calls. For example, only 3 calls occurred within 10 km of a DASAR on 8 Oct 2007 at site 3. Nonetheless, keeping in mind this low sample size caveat, the following can be concluded from these plots:

- Of the four sites analyzed, **site 2** displayed the largest north-south spread of whale call positions (at times without detectable airgun pulses from the *Gilavar* or *Henry Christoffersen*) during the middle of the season. The general trend at site 2 was for the distribution of whale calls to be farther offshore later in the season than at the beginning of the season. Koski and Miller (2002; in press) have shown that the whales passing through the eastern Alaskan Beaufort later in the season tend to be farther offshore, and that the whales farther offshore tend to be larger. However, it is important to remember that in this analysis only calls within 10 km of the nearest DASAR were included. This will almost certainly constrain the north-south extent of the apparent call distribution. Consequently, the width of the migration corridor at each site, as shown in Figure 8.20, is certainly underestimated. In addition, it is likely that the different sites will not be constrained to the same extent, because of their differing bathymetry ranges.

- **Site 3** was similar to site 2, i.e., the general trend for the distribution of whale calls at site 3 was for calls to be farther offshore later in the season than in the beginning of the season.

- **Site 4:** at this site the distribution of whale calls experienced two non-parallel oscillations during the season. First, from approximately 1 to 15 Sep, the lower quarter of the distribution remained the same distance offshore, while the upper quarter of the distribution moved northward. The second non-parallel oscillation occurred after approximately 18 Sep, when the lower quarter of the distribution moved southward, while the upper quarter of the distribution moved northward. The overall trend of the center of the distribution was to move farther from shore through time, somewhat similar to Sites 2 and 3.

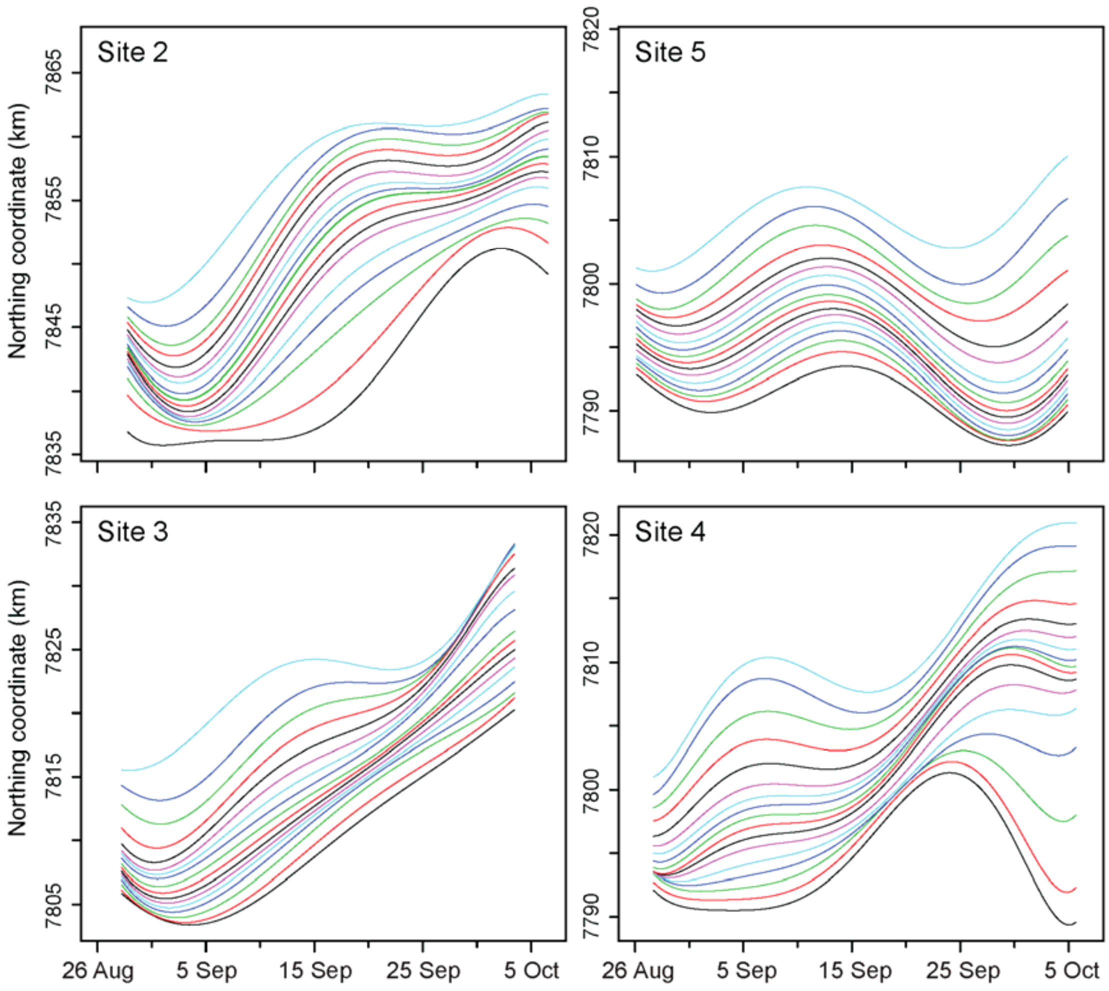

FIGURE 8.20. Estimated onshore-offshore distribution of whale calls at sites 2, 3, 4 and 5 through time when received levels of airgun pulses from *Gilavar* and *Henry Christoffersen* were absent or below background. For each site, the curves show the 10th–90th quantiles of "northing" (in steps of 5%) for "easting" positions at the middle of the four DASAR arrays. Quantiles were determined excluding calls with estimated positions >10 km from the closest DASAR. Sites away from seismic operations (2 and 5) are shown in the top plots, and sites close to seismic operations (3 and 4) are shown in the bottom plots. The easting coordinates used here were 431143.35 for site 2, 510397.25 for site 3, 550949.55 for site 4, and 415937.15 for site 5. Ticks on y-axes are all 5 km apart.

- **Site 5:** quantiles of the distribution of calling whales were remarkably parallel and confined to a relatively narrow band approximately 10–15 km wide. This could to some extent be related to the bathymetric features at site 5, which is off a headland (just east of Kaktovik) where water depth increases more rapidly with distance from shore than at any of the other sites (Fig. 8.3). The distribution of calls at site 5 oscillated in a regular manner onshore and offshore, with a period of approximately 20 days.

When Shell seismic operations were ongoing ***and*** seismic sounds from *Gilavar* and *Henry Christoffersen* were above background, certain parts of the call distribution at some sites tended to change location. Figure 8.21 shows the change in each quantile per 1 dB increase in received sound level. Changes >0 imply that the location of the call distribution represented by that quantile tended to be farther north when estimated received levels of airgun sounds increased in strength. Changes <0 (as for site 3, Fig. 8.21) imply the opposite. Keeping in mind that few calls were received during seismic operations at sites 3 and 4 and that analysis was restricted to calls within 10 km of the nearest DASAR, the following are some general results:

- **Site 2**: whales near the 30th and 35th quantiles (~1/3rd across the monitored part of the migration corridor, which was limited to calls within 10 km of the closest DASAR) tended to increase their offshore distance by ~130 m for every 1 dB increase in received levels of *Gilavar*'s and *Henry Christoffersen's* airgun pulses above background (Fig. 8.21; "full array" method, see section *Analyses of the Received Levels of Seismic Pulses at Whale Call Locations*). The relationship was less strong for higher quantiles (farther offshore).
- **Site 3**: the lower 2/3rd of the call distribution tended to be closer to shore with increasing received levels. For every 1 dB increase in received level ("full array" method), the lower 2/3rd of the distribution was closer to shore by ~250 m. Given the location of seismic operations between sites 3 and 4 (Fig 8.11) and the general westward direction of migration, the few whales that called at site 3 may have avoided seismic operations by deflecting south, or the southernmost whales at site 3 were calling at a higher rate because they were farther from seismic activities than other whales. Either scenario would lead to the observed negative relationship between levels of received sound and offshore coordinate.
- **Site 4**: for every 1 dB increase in received level ("full array" method), the upper 1/3rd of the distribution was farther offshore by ~300 meters. This is consistent with the location of the seismic activities relative to Site 4 (Fig. 8.11): some seismic operations occurred within the southwestern portion of the area monitored by the site 4 DASARs. Given the average west-northwest direction of bowhead migration in this area, most whales likely perceived the seismic operation to be south of their path, and may have either ceased calling or deflected northward (or some combination of the two). Either cessation of calling or deflection northward (or both together) would cause the observed relationship between received levels and the upper quantiles of the distribution.
- **Site 5**: there was no statistically significant relationship between offshore position and received sound levels from *Gilavar*'s and *Henry Christoffersen's* airgun pulses at site 5.

SUMMARY AND CONCLUSIONS

This study aimed to assess the effects of seismic exploration on the behavior of bowhead whales during their autumn migration. A passive acoustic approach was used. Thirty-five **d**irectional **a**utonomous **s**eafloor **a**coustic **r**ecorders (DASARs) were deployed at 5 sites in the Alaskan Beaufort Sea, spread over an alongshore distance of ~280 km (174 mi), from north of Kaktovik (Barter Island) in the east to Harrison Bay in the west. DASARs were deployed in mid- to late-August and retrieved in early- to mid-October, recording for 46–50 days at a 1 kHz sampling rate. Over 168,000 bowhead whale calls were detected by all DASARs combined. Of these, more than 129,000 had a location estimate, 89,374 of which were within 10 km of the nearest DASAR at any of the sites. (Some analyses were limited to a 10 km range around each site because the detectability of calls and accuracy of locations both decrease steeply beyond a few kilometers, depending on call strength and background noise interference.)

Call location rates (i.e., call detection rates for calls with a location estimate) were compared *before*, *during*, and *after* seismic activities by Shell. Seismic activities were mainly located in an area between two

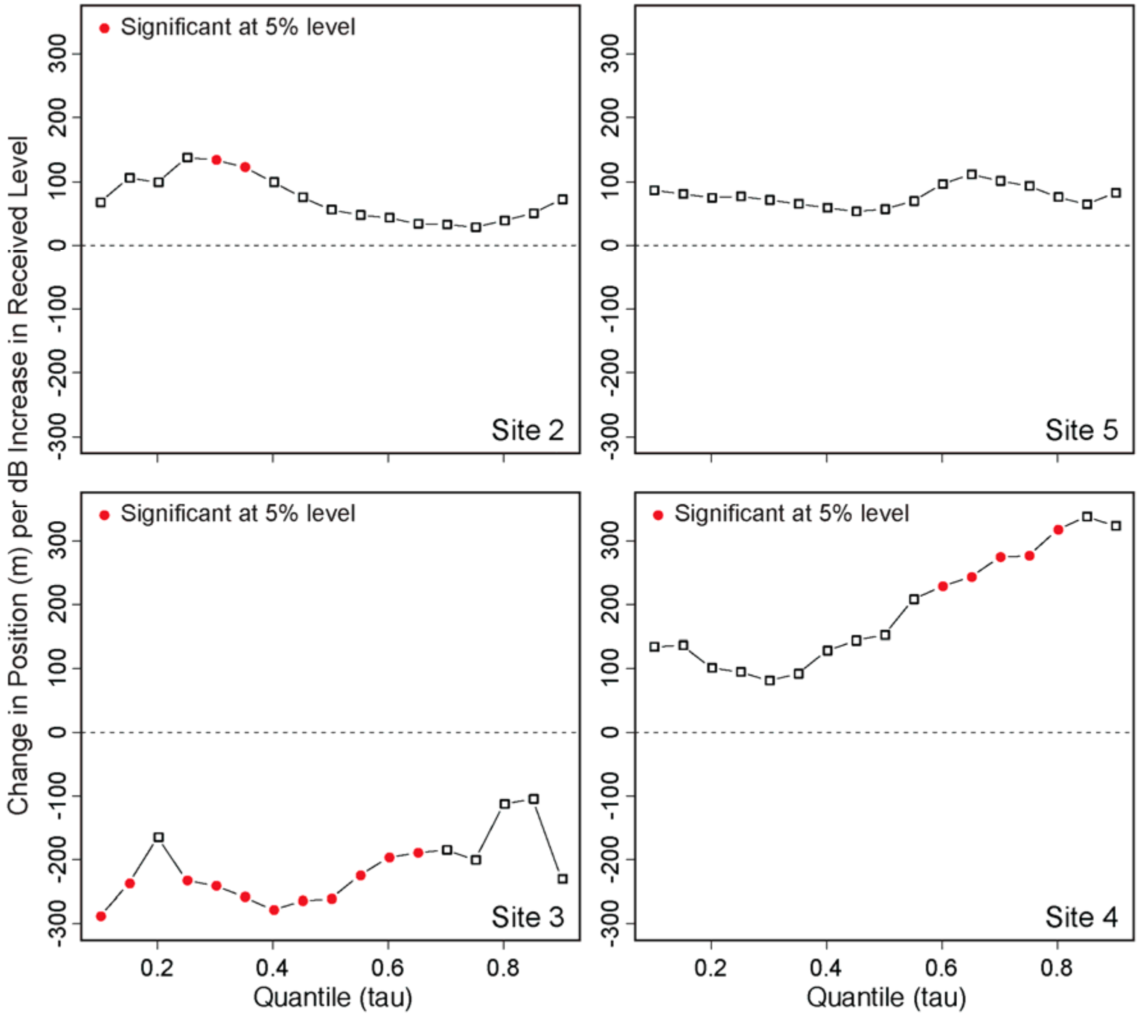

FIGURE 8.21. Slope (= change = estimated β_2 coefficient) of the relationship between estimated received sound levels from *Gilavar*'s and *Henry Christoffersen's* airgun pulses when above background and parts of the offshore call distribution represented by quantiles between 0.1 and 0.9 (10% and 90%), for sites 2, 3, 4, and 5. Sites away from seismic operations (2 and 5) are shown in the top plots, and sites close to seismic operations (3 and 4) are shown in the bottom plots. Red dots represent coefficients that were significantly different from 0 when tested using the block permutation of call clusters described in *Methods*.

of the sites (3 and 4). To account for the effects of sea state (wind speed and wave height) and natural fluctuations in the timing and location of the bowhead migration corridor, call location rates *before*, *during*, and *after* seismic activities were compared between sites *near* the activities (sites 3 and 4, on average 29 and 18 km away) and sites *far away* from seismic activities (sites 2 and 5, on average 112 and 105 km away, respectively). The analysis showed that call location rates dropped significantly at the *near* sites at the onset of seismic activities (but not at the *far away* sites). Based on the acoustic data alone, it was not possible to distinguish whether this was due to an interruption in calling activity, or deflection of the whales out of the area of seismic activities. However, results from the aerial surveys (Chapter 7) suggest little deflection during seismic activities, seemingly in large part because of the presence of food patches where whales were feeding. It therefore seems like the drop in call location rates was mainly due to a change in calling behavior by the whales, and less due to deflection.

Received levels of airgun sounds (from Shell seismic vessels) were estimated for each whale call location using information on the location of the seismic ship and the number of airguns used, as well as propagation models obtained from sound source verification (SSV) measurements and confirmed with data recorded by the DASARs. One of our analyses was limited to call locations within 10 km of the nearest DASAR, and it was assumed that the maximum number of guns was used whenever a seismic ship was operating. In this case, the percentage of calls exceeding received levels (rms) of 120 dB, 140 dB, and 180 dB were as follows (sites 2 and 5 are "far away", sites 3 and 4 are "near" seismic operations): site 2, 1.7%, 0%, and 0%; site 3, 93%, 20%, and 0%; site 4, 94%, 44%, and 0.004%; site 5, 0.6%, 0%, and 0%.

The estimated quantiles (percentiles) of the onshore-offshore distribution of bowhead calls were computed as a function of date for each site, for times when received sound levels of airgun pulses from the *Gilavar* or *Henry Christoffersen* were either absent or below background. For site 5 the quantiles showed a regular onshore-offshore oscillation with a period of approximately 20 days. Site 2 was similar to site 3, with a gradual offshore shift of whale call positions over the season. At site 4 the overall trend of the center of the distribution was to move farther from shore over the season, as for sites 2 and 3. However, site 4 also differed in the presence of two non-parallel oscillations over the season, i.e., alternating periods of spreading out and tightening of the call locations. Effects on these call distributions were also examined when received levels of seismic pulses from the *Gilavar* or *Henry Christoffersen* were above background. At site 2, for every 1 dB increase in received level from seismic pulses, whales close to the 30th quantile increased their offshore distance by ~130 m ($p<0.05$). At site 5 there was no statistically significant relationship between offshore position and received sound levels of seismic pulses. At the sites close to seismic operations (sites 3 and 4) effects were more pronounced. At site 3, for every 1 dB increase in received level from seismic pulses, the lower 2/3rd of the call distribution tended to be closer to shore by ~250 m. At site 4, for every 1 dB increase in received level from seismic pulses, the upper 1/3rd of the call distribution was farther offshore by ~300 m. The shifts in call position at sites 3 and 4, as a result of increased received levels of sound from seismic pulses, can be explained by whales deflecting away from the area of seismic operation, or by an interruption in calling by the whales closest to the seismic vessel.

In summary, the effects of airgun sounds on the calling behavior of bowhead whales were examined from the perspective of changes in call detection rates and changes in call distribution. The first analysis showed a statistically significant decrease in call detection rates with onset of seismic activities, and the second analysis showed significant shifts in call distribution with increasing received sound levels from seismic pulses. The acoustic method does not allow us to distinguish whether a change in the frequency and location of whale calls is due to a change in calling behavior (whales stop calling), or a change in whale location (whales deflect away). Most likely it is a combination of both. However, results from the aerial surveys in 2007 as well as some of our own results indicate that deflection due to the seismic survey may have played a smaller part in these changes than expected, with a concomitant larger part of our results explained by changes in calling behavior.

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9. OTHER INDUSTRY AND AGENCY STUDIES [1]

In addition to the studies conducted by SOI as described in the earlier chapters of this report, other industry–sponsored studies were conducted by several companies in support of development activities in offshore areas of the Beaufort Sea during the open–water period 2007. No additional industry–sponsored studies were conducted in the Chukchi Sea. Pioneer Natural Resources Alaska, Inc. (Pioneer) conducted acoustic and aerial surveys in support of an offshore drilling island in Harrison Bay. FEX LP (FEX) conducted barge activity between West Dock and Cape Simpson in support of exploratory activities in the National Petroleum Reserve–Alaska (NPR–A). BP Exploration (Alaska) Inc. (BPXA) conducted ongoing acoustic studies in support of oil production activities at Northstar Island. In addition to these industry studies, the Minerals Management Service (MMS) has funded the Bowhead Whale Aerial Survey Program (BWASP) during each year from 1979 to the present to document bowhead whale movement patterns during fall migration through the Beaufort Sea. Since 2005 the National Science Foundation has funded the multidisciplinary Study of Northern Alaska Coastal Systems (SNACS) to develop a systems approach to environmental study in the Arctic. Activities of the SNACS program were ongoing in 2007 and most data are still under analysis. In 2007 the National Marine Mammal Laboratory, Alaska Fisheries Science Center, and National Marine Fisheries Service began the multi–year Bowhead Whale Feeding Ecology Study (BOWFWST) during the summer near Barrow (Goetz et al. 2008). A discussion of the preliminary results of these studies is presented below. Detailed reports describing the methods and results of these studies are available from Pioneer, BPXA, FEX, and MMS.

BP (NORTHSTAR)—ACOUSTIC STUDIES 2007 [2]

Introduction

Since 2000, BPXA has used passive acoustic techniques to monitor the bowhead whale fall migration north of Northstar Island for a nominal 30 day period each year. Every year since 2001, continuous underwater recordings were obtained close to Northstar Island to determine the levels and frequency composition of sounds produced by activities on the island itself and by associated vessels. In 2000 to 2004, whale calls were monitored continuously by an array of Directional Autonomous Seafloor Acoustic Recorders (DASARs) deployed 6.5–21.5 km (4–13.4 mi) north–northeast of Northstar. The key objective of the monitoring in 2001–2004 was to estimate the offshore displacement of the southern edge of the bowhead migration corridor, if any, at times when higher–than–average levels of underwater sound were being emitted from Northstar Island and its associated vessels. Overall, the offshore distance of the apparent southern (proximal) "edge" of the migration corridor was significantly ($P < 0.01$) associated with industrial sound output each year. The best estimates of the offshore deflection of the southern part of the migration corridor at times with high Northstar sound ranged from a low of 0.8 km (0.5 mi) in 2003 to a high of 2.2 km (1.4 mi) in 2004.

During the bowhead whale migration in Sep 2007, Greeneridge Sciences (on behalf of BPXA) implemented an acoustic monitoring program north–northeast of BPXA's Northstar oil development. Monitoring objectives in 2007 were identical to those in 2005 and 2006, but modified relative to those in earlier years. Results based on data collected in 2001–2004 had suggested that the bowhead migration corridor offshore of Northstar likely was not strongly affected by varying activities at Northstar. In

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[1] Robert Rodrigues and Darren Ireland, LGL Alaska Research Associates, Inc., Anchorage, Alaska.

[2] Summarized by LGL from a detailed technical report by Greeneridge Sciences, Inc. (Blackwell et al. 2008).

addition, the North Slope Borough's Science Advisory Committee (SAC) concurred that priority be put on additional analyses of the 2001–2004 data over additional intensive data collection.

The specific objectives in 2007 were:

(1) to measure near–island sounds about 450 m (1476 ft) north of Northstar using DASARs and to compare the amplitude and frequency composition of the sounds with similar data collected in previous years;

(2) to install a small array of DASARs in four of the locations used in previous years (see below), obtain whale call counts from one DASAR, and compare the counts with those obtained at the same location in 2001–2006;

At the end of the season a decision was made to analyze whale calls from DASARs at all three locations in the offshore array. The additional analyses allowed for comparisons of call counts at more DASAR locations and added two other objectives to those described above:

(3) obtain bearings to whale calls and localization of calls, if possible. A comparison of the bearings or locations obtained in 2007 with those obtained in previous years should provide information on the distribution of the calling whales, i.e., the proportion of calls originating offshore vs. inshore of the locations of the DASARs deployed in 2007; and

(4) compare the types of calls recorded at DASAR locations used in 2007 with the call types recorded at the same locations in previous years.

Methods

Seven DASARs were deployed from the ACS vessel *Gwydyr Bay* on 28 Aug 2007. Ice conditions were very different from 2005 and 2006 when abundant pack ice delayed deployment of the DASARs by up to a week. No pack ice was seen during deployments in 2007. Two near–island DASARs (NSb and NSc) were deployed ~410 m and 480 m (1345–1575 feet) northeast of Northstar's north shore (Fig. 9.1). Another five DASARs were deployed in the offshore array, in locations CC, EB (2 recorders), CA, and NE. These DASARs were 11.4–21.4 km (6.2–11.6 n.mi. or 7.1–13.3 mi) NNE of Northstar Island (Fig. 9.1).

All seven DASARs started recording on 28 Aug and an acoustic transponder in each DASAR was interrogated to confirm that each was operating nominally. DASAR clocks and orientation were calibrated by projecting test sounds at 21 locations (Fig. 9.1) on 28 Aug and 30 Sep. All seven DASARs recorded continuously at a 1 kHz sampling rate until they were retrieved on 3 Oct 2007.

Results

The signals from one of the near–island DASARs (NSb) were analyzed to determine the broadband (10–450 Hz) level of underwater sound based on a one–minute analysis every 4.37 minutes. The combined results are presented as a sound pressure time series (SPTS) in Fig. 9.2B for the period 28 Aug–3 Oct 2007. The range of broadband levels obtained for DASAR NSb in 2007 was 91–133 dB re 1 μPa. This was similar to ranges obtained in 2002, 2003, 2004, 2005, and 2006, which were 90–135, 90–137, 92–133, 88–136, and 90–131 dB re 1 μPa, respectively. Broadband levels close to Northstar are determined by a combination of two factors: sound–generating industrial activities at and near Northstar, which are dominated by vessels when present, and wind speed, which determines ambient sound levels. Mean hourly wind speed, as recorded by the Endicott weather station, is shown in Fig. 9.2A for the 2007 field season.

Fig. 9.3 shows broadband (10–450 Hz) levels of sound as recorded at the near–island recorders in 2001–2007. In all years baseline levels (the lower edge of an "envelope" around the plotted sound pressure time series) were mainly determined by wind. Baseline levels of island sound were higher in 2007 than in 2006. This was likely a result of the higher wind speeds in 2007 and the lack of ice around the island and in the DASAR array.

Vessel round trips from West Dock to Northstar during the 28 Aug to 3 Oct 2007 DASAR recording period were made by the hovercraft (41 trips), tugs (13 trips; usually accompanied by a barge), and ACS vessels (76 trips). Vessel traffic to and from Northstar in 2007 increased compared to 2006, but was still below 2001–2003 levels. Round trips to the island by tugs and ACS vessels combined (including trips for the acoustic work) accounted for ~75% of all the large "spikes" in DASAR NSb's sound pressure time series (Fig. 9.2B). Overall, industrial sounds from Northstar in 2007 were about the same as in 2004–2006, except for the increased frequency of transient high–level sounds associated with boats.

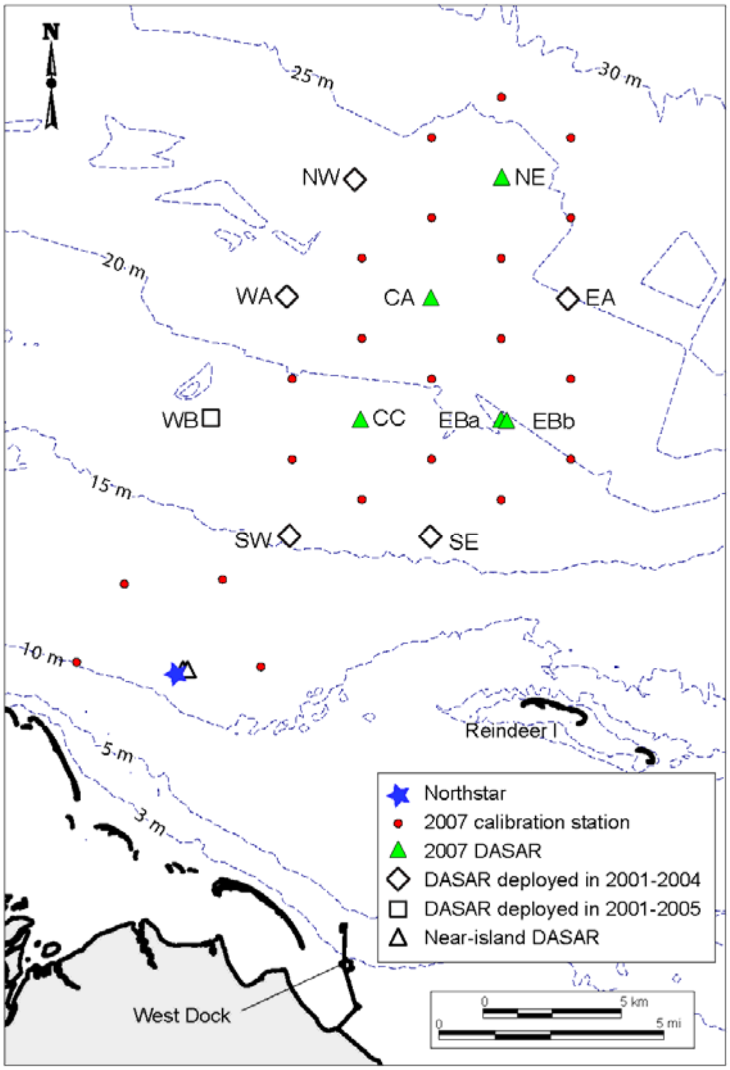

FIGURE 9.1. Locations of DASAR deployments near Northstar Island since 2000 including locations of five array DASARs, 21 calibration stations, and two near–island DASARs with respect to Northstar Island in 2007. Calibrations were performed at all calibration locations after deployments on 28 Aug, and on 30 Sep 2007 before retrievals.

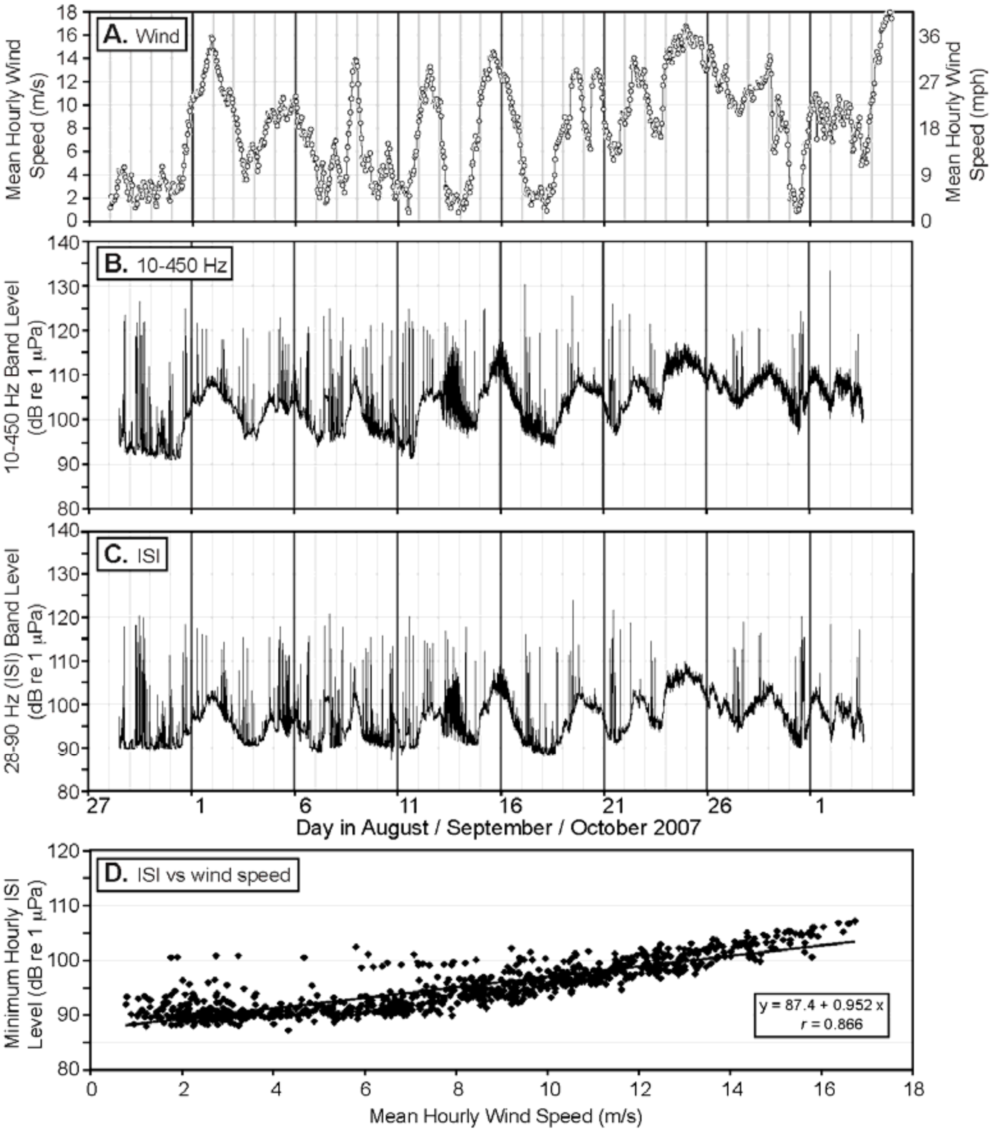

FIGURE 9.2. Variation in levels of underwater sound near Northstar in relation to date/time and wind speed, 28 Aug–3 Oct 2007. ***(A)*** Mean hourly wind speed as recorded by the Endicott weather station. ***(B)*** Broadband (10–450 Hz) levels of underwater sound near Northstar vs. time, as recorded by DASAR NSb. This recorder was deployed 410 m (1345 ft) north of Northstar. ***(C)*** Corresponding ISI band level (~28–90 Hz) from DASAR NSb. ***(D)*** Minimum hourly ISI level versus mean hourly wind speed at Endicott, for the 2007 field season.

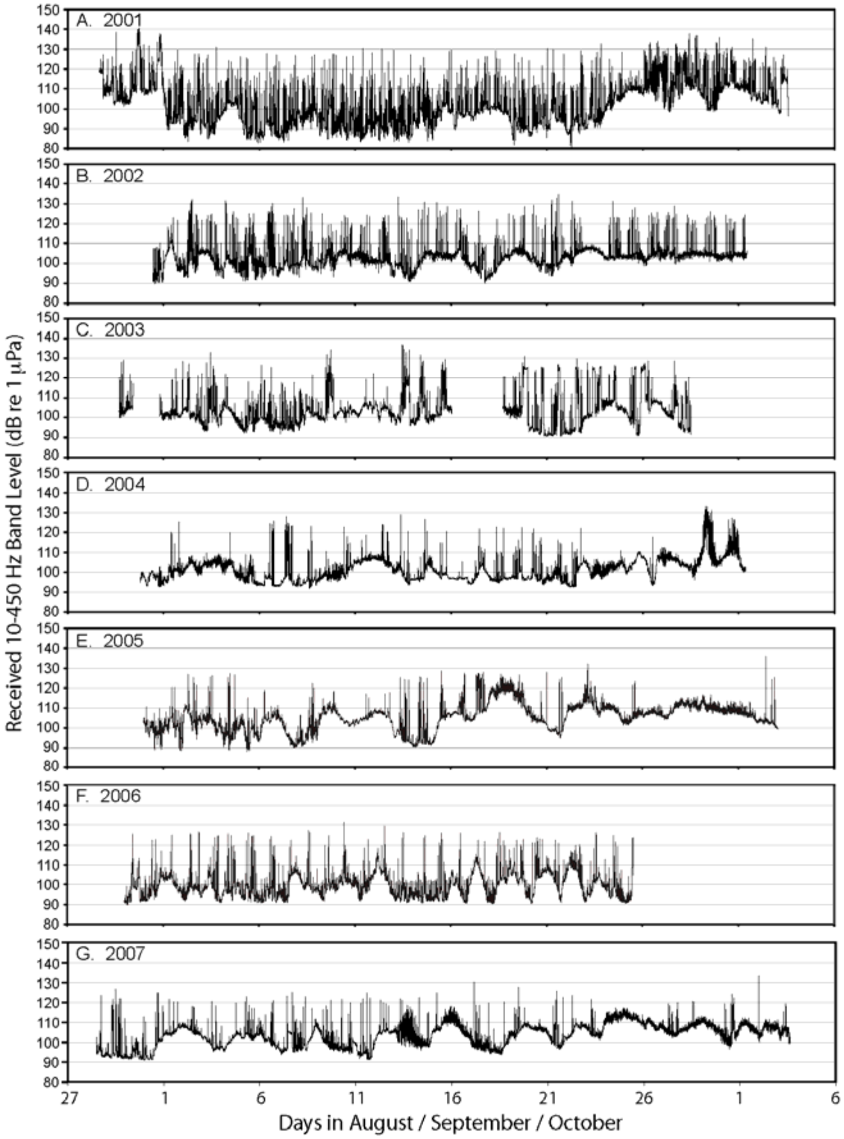

FIGURE 9.3. Sound pressure time series (10–450 Hz band level) for the 2001–2007 seasons, as recorded by the near–island recorders—a cabled hydrophone in 2001, 2002, and the first part of 2003, and a DASAR for the second part of 2003, and all of 2004 through 2007.

As in 2001–2006, the sum of sound components in the frequency range 28–90 Hz, which contains most of the industrial sound energy emanating from Northstar, defined the industrial sound index (ISI). The ISI for the 2007 study period is shown in Figure 9.2C as a function of time. As in previous years the ISI was closely related to the overall 10–450 Hz level, but the ISI is a few decibels lower as a consequence of excluding sound components at frequencies below 28 Hz and above 90 Hz. In 2007, 1–min ISI values were, on average, 6.9 dB below 10–450 Hz broadband values. This difference is somewhat greater than in previous years: it was 4.2 dB in 2006, 5.7 dB in 2005, 5.0 dB in 2004, and 5.7 dB in 2003.

A total of 12,835 calls were detected on the records of DASARs CC, EBa, EBb, CA, and NE combined during the 28 Aug–3 Oct period in 2007. Excluding NE, which was not deployed in 2006 or

2005, the total number of calls was 11,646 in 2007 compared to 1509 in 2006 (same four DASARs as in 2007) and 1613 in 2005 (DASARs CCa, CCb, EB, and WB). However the lengths of the field seasons were vastly different, with 2007 (~36 days) being about twice as long as 2006 (~18 days). Table 9.1 compares total calls detected from 2001–2007. In 2007 there were two DASARs at location EB (EBa and EBb), so to allow meaningful comparisons with previous years only one of the EB DASARs (EBa) is included in Table 9.1. Also, to allow comparison of 2007 values with all previous years, Table 9.1 only shows counts for DASARs EB and CC. The mean number of calls detected per day was calculated using only days when both recorders were functioning normally. The percentages of calls detected at CC and EB add to more than 100% because some calls were heard by both DASARs. When expressed as a number of calls per day, the 2007 call number (271 calls/day) was the third highest behind 2004 (1182 calls/day) and 2003 (895 call/day; Table 9.1).

TABLE 9.1. Comparison of bowhead whale call counts via DASARs EB (EBa in 2006 and 2007) and CC (CCa in 2005) combined in 2001–2007. Also shown for each year are mean number of calls detected per day (considering only days when both DASARs were operating), and percentages of those calls detected at each of the two DASAR locations.

			Percentages of calls detected	
Year	Total calls detected at EB and/or CC	Mean # calls per day [a, b]	EB	CC
2001	1542	110	97.2	9.3
2002	4775	208	90.2	43.0
2003	26,401	895	82.3	62.6
2004	31,903	1182	83.1	72.8
2005	1020	35	62.5	56.5
2006	677	38	49.0	57.0
2007	7312	271	91.0	67.9

[a] Mean number of calls per day for individual DASARs EB and CC were as follows: **2001**, 107 and 10, respectively; **2002**: 187 and 90; **2003**: 737 and 560; **2004**: 982 and 915; **2005**: 22 and 20; **2006**: 18 and 21; **2007**: 246 and 184. For each year, these values consider days when both of these DASARs were operating.

[b] In **2000**, the DASAR array was 1 n.mi. farther north than in 2001–2006, with no functional DASAR near EB. The recorders closest to DASAR CC were SW1 located 1850 m north of CC, and SW2 ~4650 m southwest of CC. SW1 recorded 1177 calls over 11.7 days, or 100 calls per day; SW2 recorded 1012 calls over 5.7 days, or 177 calls per day.

Figure 9.4 compares daily number of calls detected by DASARs EB and CC combined in 2007 and in previous years. In 2007, as in 2001, mean daily call detection rates were higher in the first part of the season, before 15 Sep, whereas in 2002, 2003 and 2004 mean daily call detection rates were higher after 15 Sep. The two years with the largest call counts (2003 and 2004) showed three peaks (Fig. 9.4): a small peak in early Sep, a second peak in mid–Sep, and a third (and largest) peak on 21 Sep. In 2007 the timing (close to 6 Sep) and size (in the range of 1000–1500 daily calls) of the first peak was similar to that in 2003 and 2004. However, the much larger increase in call detection rates later in the month (15–21 Sep), which occurred in 2003 and 2004, did not take place in 2007 (Fig. 9.4). The analysis of all the records from DASARs placed offshore in 2001–2007 supports the general conclusion that 2007 was an intermediate year in terms of whale call counts.

In 2007, 84.5% of the 12,835 whale calls were recorded by two or more DASARs. Figure 9.5 shows the estimated locations of these 10,845 calls in relation to Northstar and the five–DASAR array. It should be noted that uncertainty in the position estimates generally decreases as a call is heard by more DASARs. In addition, uncertainty in the position estimates increases with increasing distance from the DASARs.

The location information was used to compare the numbers of whale calls located offshore vs. inshore (O/I ratio) of the DASARs. Offshore calls were defined as those whose bearings from the DASAR of interest were between 298º and 98º True. Inshore calls were those with bearings between 118º and 278º True. These bearing ranges did not include a 20º buffer which excluded calls with bearing ranges between 98º–118º and 278º–298º. The mean bearing angle (α) was calculated using the equation $\alpha = \arctan(\bar{x}, \bar{y})$, where $\bar{x}$ and $\bar{y}$ are the average cos and sin, respectively, of all bearings obtained at one DASAR during a season. Mean vector length is a measure of the variation of individual bearings around the vector mean direction and was calculated using the equation:

$$L = \sqrt{\bar{x}^2 + \bar{y}^2}$$

In 2007 the offshore vs. inshore (O/I) ratio for DASARs EB, CC, and CA was in the range 1.7–3.3 (Table 9.2), i.e., there were 1.7 to 3.3× more calls offshore than calls inshore. These numbers are generally in the range of previous years, except for 2002, which had distinctly higher O/I ratios. In 2007 a DASAR was deployed at location NE, for which $\alpha = 109°$ (i.e., ESE) and O/I ratio = 0.9, meaning *more calls were detected inshore* than offshore. (Note that the O/I ratio has only once been below 1 for the DASARs and years shown in Table 9.2.) These results tend to indicate that the bulk of detected whale calls were south of the northern limit of the DASAR array, as also shown in Figure 9.5.

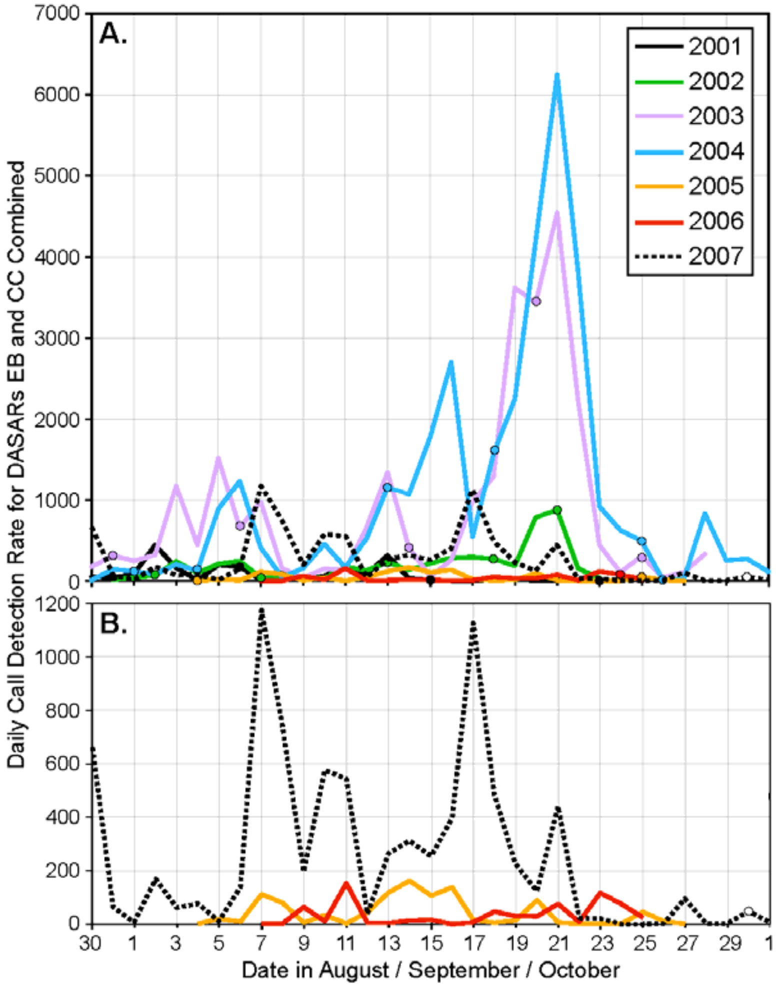

FIGURE 9.4. Daily number of bowhead calls detected by DASARs EB and CC combined for the entire 2001–2007 seasons. ***(A)*** 2001–2007, and ***(B)*** 2005, 2006, and 2007, on an enlarged scale. Daily counts marked with a dot indicate days when the acoustic vessel went into the area of the DASAR array to service the DASARs. In 2002–2007 the calls detected at those times are not included and those days are therefore "incomplete". In 2001 all calls were counted, regardless of the presence or absence of the acoustic vessel.

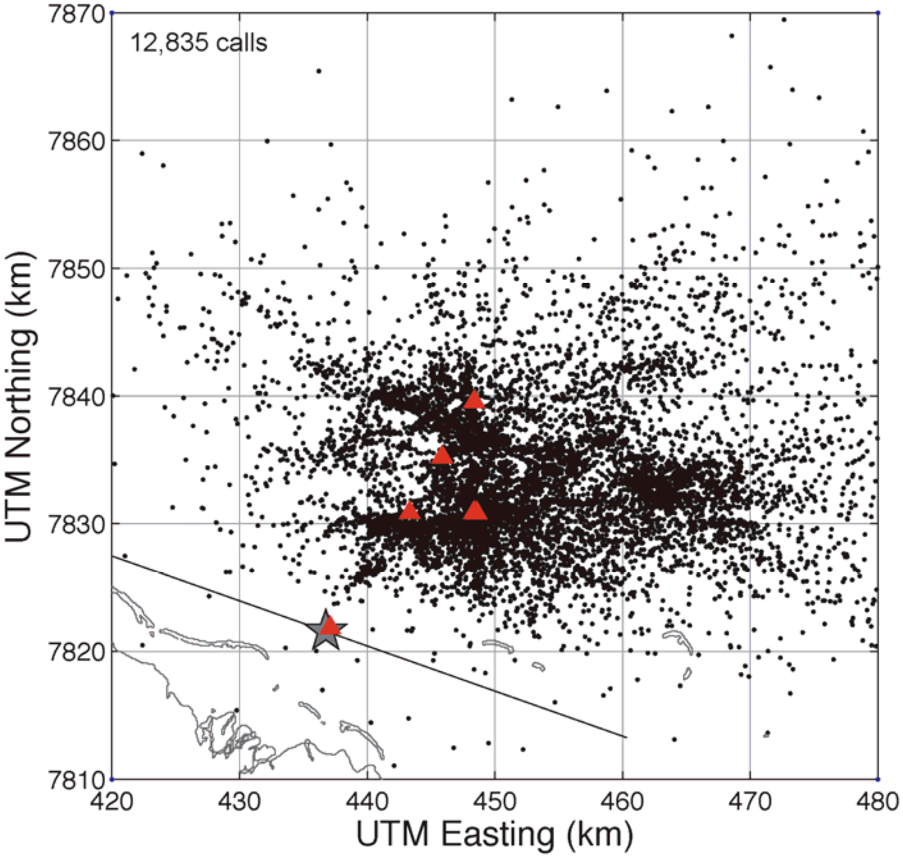

FIGURE 9.5. Estimated locations of all whale calls that were detected by two or more offshore DASARs in 2007. Northstar is shown as a gray star and the DASAR locations as red triangles.

TABLE 9.2. Results of the bearing analyses for DASARs EB (EBa in 2007), CC, and CA in 2001–2007. α is the vector mean bearing in degrees True, and L is the length of the mean vector. O/I is the ratio of number of offshore versus inshore calls. O/I ratios are shown for all years using both the old definitions of *inshore* and *offshore* (gray font) and the new definitions developed in 2007 (black font).

	EB				**CC**				**CA**			
	α (°)	**L**	***O/I***	**O/I**	α (°)	**L**	***O/I***	**O/I**	α (°)	**L**	***O/I***	**O/I**
2001	44	0.65	*6.5*	5.7	61	0.39	*2.0*	2.0	72	0.36	*1.7*	0.9
2002	64	0.74	*21.4*	13.6	51	0.66	*42.4*	28.2	42	0.55	*10.7*	5.2
2003	78	0.55	*2.9*	2.5	66	0.54	*6.4*	5.3	104	0.39	*1.0*	1.1
2004	69	0.42	*2.9*	2.4	67	0.52	*6.2*	4.4	109	0.32	*1.0*	1.1
2005	348	0.14	*1.3*	1.3	–	–	*–*	–	–	–	*–*	–
2006	33	0.46	*4.0*	4.0	308	0.04	*1.2*	1.4	38	0.45	*4.2*	3.7
2007	75	0.45	*2.9*	2.9	79	0.56	*3.7*	3.3	92	0.43	*1.7*	1.7
Mean O/I ratio:				4.62				7.37				2.30

PIONEER NATURAL RESOURCES—OOOGURUK DEVELOPMENT PROJECT

Pioneer developed an Offshore Monitoring Plan to facilitate compliance with the North Slope Borough Ordinance (serial no. 75–6–50). Pioneer and its contractors conducted two studies related to marine mammals in support of its 2007 activities at Oooguruk Drilling Site (ODS) located in Harrison Bay near the Colville River delta (Fig. 9.6). An acoustic study was conducted to measure industrial sounds resulting from activities related to construction and vessel activities in support of ODS, and aerial surveys were conducted to assess and report on the distribution of bowhead whales near ODS during fall migration. The results of these studies are summarized below.

Sound Source Characteristics of Construction Activities and Barges [3]

Underwater acoustic source level measurements of sounds from construction activities and vessels operating in the Alaska Beaufort Sea were conducted by JASCO Research Ltd. for Pioneer in Sep 2006 (Zykov et al. 2007a,b). The underwater acoustic study was continued in Sep 2007 in support of ongoing construction activities at Pioneer's ODS (Fig. 9.6). Different methodologies were used to collect underwater acoustic data for construction sounds on ODS and for vessel sounds. The 2007 study is described in detail in Laurinolli et al. (2008).

The goals of the acoustic study were to:

- measure underwater sounds associated with construction activities on ODS and the attenuation of those sounds with distance and direction from the island,
- characterize source sound levels from barging and support vessel activities and attenuation of those sounds with distance,
- assess ambient noise levels in the vicinity of ODS, and
- detect marine mammal vocalizations if present.

Measurements of underwater sound resulting from construction activities on ODS were recorded for ~two days beginning on 19 Sep 2007 at two locations north of ODS. Sound recordings were made using two Ocean Bottom Hydrophone (OBH) systems located 6.4 (N–4) and 14.5 (N–9) km (4 and 9 mi) north of ODS, respectively. Water depth at ODS was 1.0–1.2 m (3–4 ft). OBHs were deployed in water depths of ~5 and 13 m (16 and 43 ft) for N–4 and N–9, respectively.

Construction equipment on ODS during the study period consisted of various types of heavy equipment and generators. Equipment used frequently on ODS during the monitoring period included Volvo L120C and Volvo L180E loaders, and an Ingersol VR1056C material handler. A Grove RT890E crane was used intermittently.

No sounds that could be attributable to activities on ODS were audible above ambient noise in the recordings at N–4 or N–9 in 2007. This was also the case when similar measurements were made in 2006. Vessel sounds were generally not audible on either OBH, however, a weak, below–ambient tone was audible on the N–4 OBH on 23 Sep. The tone may have resulted from the tug *Kavik River* holding position at ODS. Ambient sound levels were essentially identical at both stations in 2007 and ranged from 105 to 110 dB (rms). Ambient levels in 2007 were greater than those recorded in 2006 due to higher wind and wave conditions in 2007.

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[3] Summarized by LGL from a detailed technical report by JASCO Research Ltd. (Laurinolli et al. 2008).

Vocalizations of marine mammals were recorded from both the N–4 and N–9 OBHs over a small fraction of the recording period. The vocalizing animals were thought to be ringed and bearded seals, and bowhead whales.

Measurements of underwater sound resulting from vessel activities were recorded for two vessels, the crew boat *American Resolution* and the self–propelled barge MV *Garrett,* as they transited between Oliktok Dock and ODS (Fig. 9.7). Two OBHs were suspended in the water column and tethered from a vessel anchored along the barge route between Oliktok Dock and ODS. Measurements of the *American Resolution* and the *Garrett* were made as they passed the anchored vessel at standard transit speeds.

The *American Resolution* was 10.4 m (34 ft) in length and equipped with twin 300 hp John Deere inline 6–cylinder diesel engines attached to a twin 273 Hamilton Jet Direct Drive. The vessel had a seating capacity of 32 and sound measurements were made at a transit speed of 33 kt. The self–propelled barge *Garret* was 42.7 m (140 ft) in length and equipped with two 220 hp diesel engines with two 40–in, 4–blade propellers. The full–load capacity of the *Garrett* was 600,000 lbs and the transit speed was 5.5 kt.

Two underwater sound measurements were made for the *American Resolution.* Broadband source levels for the *American Resolution* were 169.7 and 173.5 dB re µPa rms and sound levels were predicted to drop to 120 dB (rms) at ~650 m (2133 ft).

Two underwater sound measurements were also made for the *Garret*. Broadband source levels for the *Garrett* were 172.5 and 175.1 dB re µPa rms and sound levels were predicted to decrease to 120 dB (rms) at ~560 m (1837 ft).

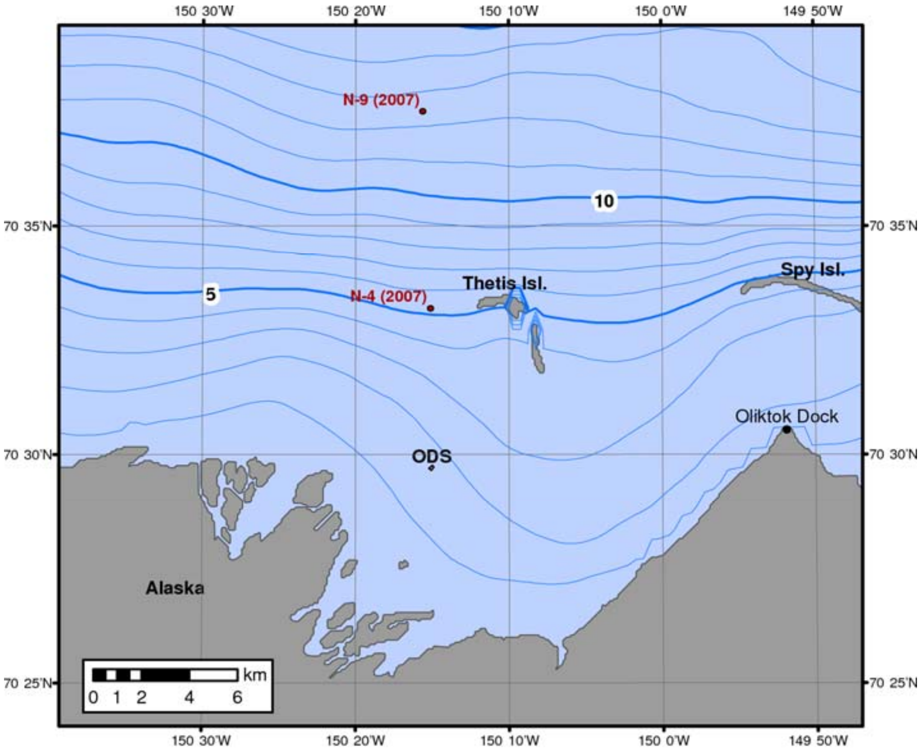

Figure 9.6. Oooguruk Drillsite (ODS) and OBH deployment locations for Pioneer's 2007 acoustic survey. Water depth is shown in meters. Figure is from Laurinolli et al. (2008).

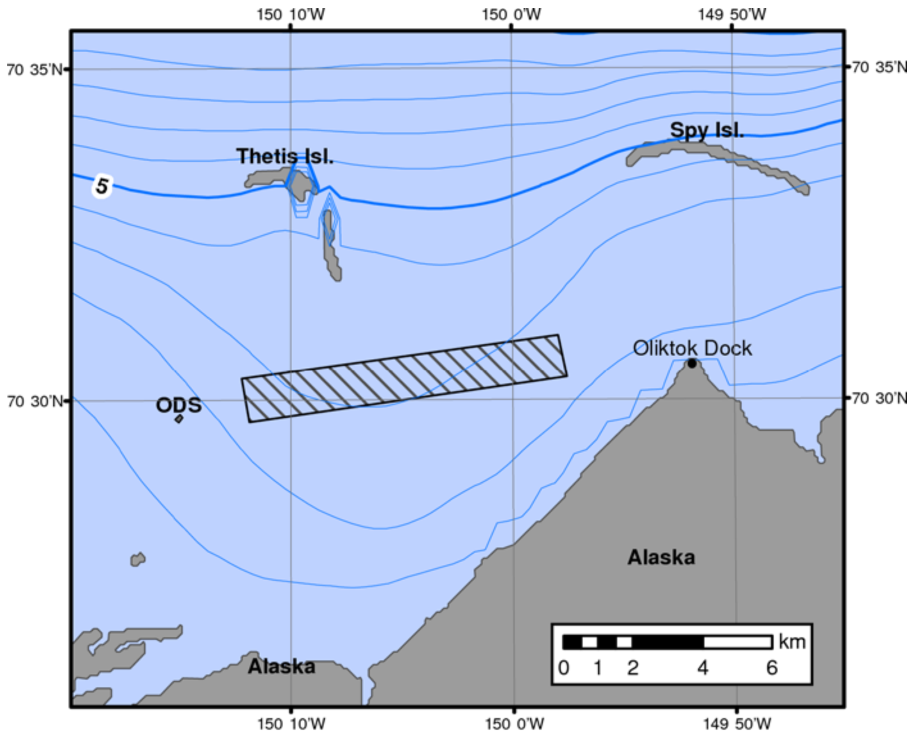

FIGURE 9.7. Location of underwater source level measurements for vessels transiting between Oliktok Dock and ODS in 2007*.* Depth contours have 1–m intervals. Figure is from Laurinolli et al. (2008).

Aerial Surveys[4]

NSB permit conditions required Pioneer to "assess and report on the distribution of bowhead whales within 15–20 miles (24–32 km) of the island during fall migration." Pioneer developed an aerial survey program to assess the distribution of bowhead whales near ODS during Sep 2006 (Reiser et al. 2008). This study was repeated in Sep and Oct 2007 and was described in detail in Williams et al. (2008).

The survey was centered north of the ODS in Harrison Bay and encompassed an area approximately 580 km^2 (224 mi^2; Fig. 9.8). It consisted of four north–south transects, each of which was ~24 km (15 mi) in length and separated by ~9 km (5.6 mi). The southern boundary of the survey area was located approximately 7 km (4.3 mi) north of the ODS at a latitude equivalent with the northern edge of Thetis Island. The area's northern boundary was approximately 31 km (19.3 mi) north of the development site and 24 km (15 mi) north of Thetis Island. The east and west boundaries spanned a distance of approximately 24 km (15 mi). Water depth within the surveyed area ranged from ~2 to 10 m (6.6 to 32.8 ft).

Aerial surveys were flown with a Bell 412 helicopter at an altitude of ~457 m (1500 ft) and an air speed of 185 km/hour (115 mph). The preseason plan was to fly two surveys per week from mid–Sep to early Oct. Weather conditions were expected to occasionally limit effort due to limitations of the minimum survey altitude required to prevent unauthorized harassment of marine mammals.

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[4] Summarized by LGL from a detailed technical report by LGL (Williams et al. 2008).

Surveys were conducted by two trained observers. Each observer recorded the time, visibility (subjectively classified as excellent, good, moderately impaired, seriously impaired or impossible), sea conditions (Beaufort wind force), ice cover (in 10ths) and sun glare (none, moderate, severe) at the start and end of each transect, and at two–minute intervals along transect.

Observers focused their search efforts to one km from their respective sides of the helicopter resulting in a two km–wide band of intensive coverage. Each observer carefully searched the transect area for evidence of bowhead whales, polar bears (*Ursus maritimus*), and seals (seals were typically unidentifiable to species from survey altitudes). For each marine mammal sighting, observers recorded the species when determinable, number, size/age/sex class when determinable, activity, heading, swimming speed category (if traveling), sighting cue, ice conditions (type and percentage), and inclinometer reading. The presence of boats was also noted. A sighting was considered *on–effort* if it occurred while the helicopter was on an established north–south oriented survey track and *off–effort* if it occurred while transiting between survey tracks.

Eight surveys were flown or attempted from 14 Sep through 4 Oct. One survey was terminated due to poor visibility after completing only 6.4 km of effort. No bowhead whales were observed on transects, although a group of four bowheads (three adults and one subadult) was recorded north of Transect 1 on 3 Oct approximately 35 km (21.7 mi) north northeast of ODS. Only one marine mammal was observed while observers were on effort. An unidentified seal was recorded on Transect 1 on 20 Sep. Other marine mammal sightings included 10 seals near the mouth of the Colville River on 3 Oct, and a polar bear on Spy Island on 17 Sep.

There was no evidence from the aerial survey data to suggest that bowhead whales traveled within 20 miles of the ODS in substantial numbers. Underwater acoustic recordings (Laurinolli et al. 2008) made during the same period as Pioneer's aerial surveys detected bowhead vocalizations during a small percentage of the sampling period suggesting that bowhead whales were in the general area of ODS, however no locations for vocalizing bowheads were determined. Survey data from other studies indicated that large numbers of bowheads were in the greater region at the time of the Pioneer surveys, and the fall whaling season was successful in Kaktovik, Nuiqsut, and Barrow. Reports on aerial surveys by MMS (BWASP MMS 2007) have records of 86 bowhead whale sightings within 32 km (20 mi) of ODS. Many of these sightings were recorded opportunistically during "search" periods when the aircraft was not following an established transect leg. The average distance of these 86 sightings from ODS was 22 km (14 mi) with a minimum distance of 9 km (5.5 mi).

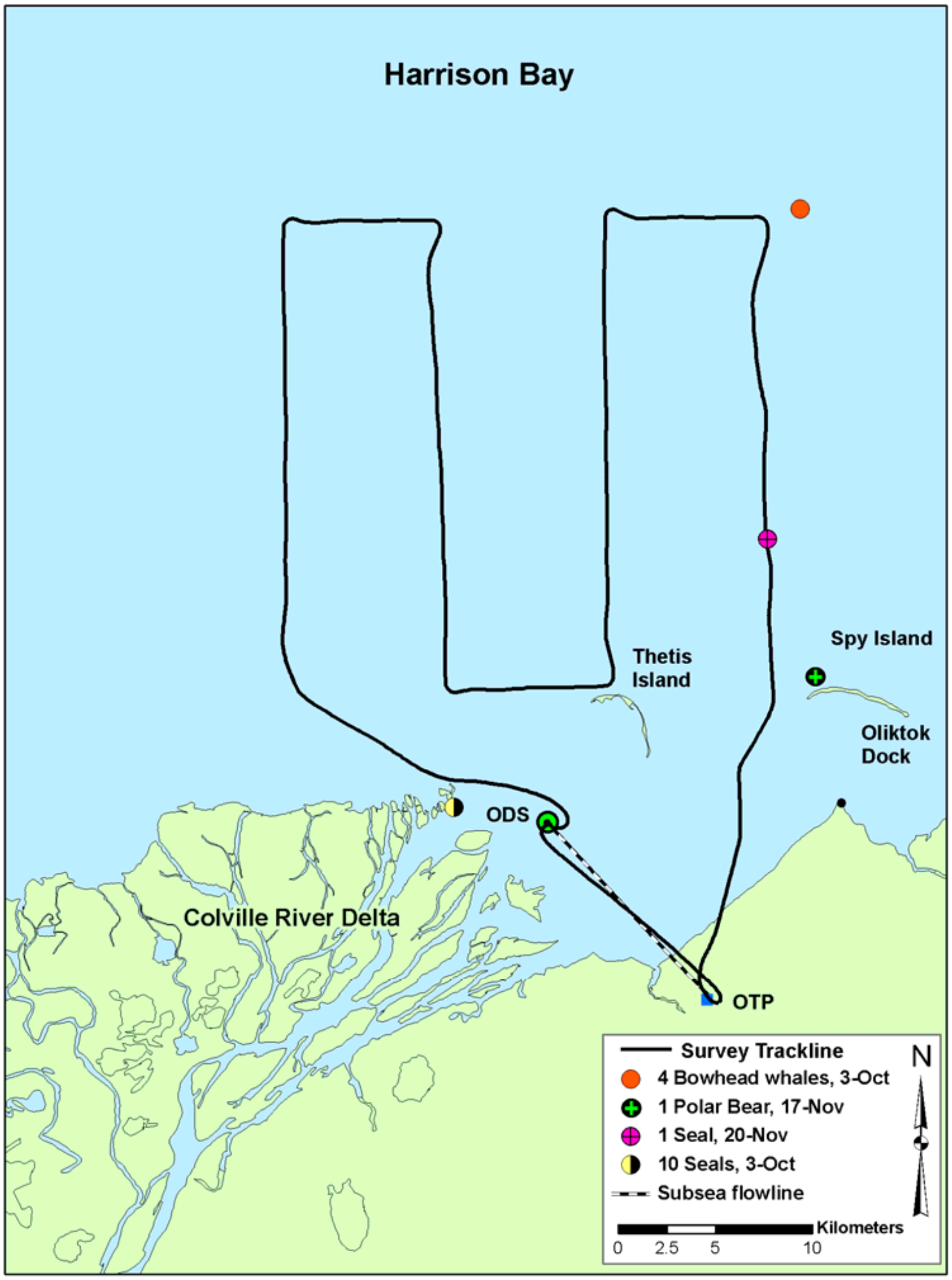

FIGURE 9.8. Aerial survey trackline showing locations of the four north–south transects from the 25 Sep 2007 survey and marine mammal sightings during the 18 Sep through 4 Oct 2007 survey period. Data are from Williams et al. (2008).

FEX LP BARGE–TRAFFIC MONITORING[5]

FEX conducted barging activities between West Dock and Cape Simpson in support of oil and gas exploration in the National Petroleum Reserve–Alaska. A marine mammal monitoring program as required under an Incidental Harassment Authorization granted to FEX by the National Marine Fisheries Service (NMFS) was conducted from 31 Jul through 24 Aug in conjunction with the barging activity (Green et al. 2007). During this period 10 round–trips were made by barges and marine mammal observers (MMOs) onboard the barges searched for and recorded observations of marine mammals from the bridge or catwalk. MMOs also recorded environmental variables and behavior of marine mammals.

In total, 901 seals were recorded by MMOs during the 10 barge round trips, most of which (~76%) were ringed seals. Approximately 18% of the seals could not be identified to species. Spotted seals comprised ~5 % and bearded seals < 1% of the seal total.

Ringed seals were recorded along the entire barge route between West Dock and Cape Simpson. Spotted seals were most abundant from eastern Harrison Bay to Cape Simpson. Most bearded seals were recorded in Harrison Bay. Most seals showed no reaction or reacted mildly to the barge activity.

MMO's identified 38 bowhead whales, 10 gray whales, and two humpback whales during the barge activities. One additional whale was unidentified. All whale sightings were recorded in Smith Bay. All bowhead sightings occurred from 15 through 18 Aug although the lack of bowhead sightings after 18 Aug may have been a result of poor sighting conditions during the latter portion of the season. There was little whale reaction to the barge traffic. The two humpback whales appeared to be curious as they approached the barge slowly. No other whale responses to the vessels were recorded by MMOs.

MMOs also recorded five polar bear sightings of six bears. Most polar bears were sighted on ice flows although one polar bear was observed swimming in open water west of Thetis Island. One polar bear reacted strongly to the barge by diving from one ice floe and swimming to another. Other bears had only mild reactions to the presence of the barges.

BOWHEAD WHALE FEEDING ECOLOGY STUDY[6]

The National Marine Mammal Lab (NMML) and NOAA Fisheries began the Bowhead Whale Feeding Ecology Study (BOWFEST) in 2007. The study focused on late summer oceanography and prey densities relative to whale distribution over continental shelf waters within 100 miles north and east of Point Barrow, Alaska. Through NOAA's cooperative institutes, researchers from Woods Hole Oceanographic Institute, University of Rhode Island, University of Alaska Fairbanks, University of Washington, and Oregon State University were included. Field work was coordinated with the North Slope Borough, Alaska Eskimo Whaling Commission, Barrow Whaling Captains' Association, Alaska Department of Fish and Game, and the Minerals Management Service. Marine mammal studies were permitted under NMML's Permit No. 782–1719. Components of the BOWFEST program included aerial surveys, acoustical monitoring, tagging and oceanographic studies, and tissue analyses from harvested whales. Much of the data of the 2007 BOWFEST program are currently undergoing analysis. Available results of the various components of the 2007 BOWFEST study are summarized below.

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[5] Summarized by LGL from a detailed technical report by Tetra Tech (Greene et al. 2007).

[6] Summarized by LGL from annual reports provided by NMML and study participants.

Aerial Surveys in the Vicinity of Barrow, Alaska, Aug–Sep 2007

Aerial surveys were conducted in the Beaufort Sea from 22 Aug through 11 Sep 2007 (Goetz et al. 2008). The study area was divided into two parts and located offshore of northern Alaska generally east and north of Barrow (Fig. 9.9). The two sections were 7276 and 12,152 km^2 (2809 and 4691 mi^2), respectively. Two NOAA Twin Otter aircraft were used to fly predetermined transect lines on 6 days during the study period with a total survey flight time of 30.8 hr. Two observers and a computer operator recorded environmental data and marine mammal sightings. A laptop computer interfaced with a portable GPS to record position data automatically. Specific data entries for weather included overall percent ice cover, ice type, sky condition, and sea state (on a Beaufort scale) as well as glare, visibility angle, and visibility quality for each side of the aircraft. Observers used an inclinometer to determine the searchable distance from each side of the aircraft. Date, time, sighting observer, inclinometer angle, group size, species, and reaction to plane were recorded for all marine mammals; in addition, for bowhead whale sightings, observers reported calf number, travel direction, sighting cue, dominant behavior, group composition, and number of nearby vessels.

Two Nikon D200 cameras with 50 mm and a 180 mm lenses were used to collect photoidentification and photogrammetry data. Photographs of a calibration target used as a reference for determining whale lengths were taken with these cameras and lenses.

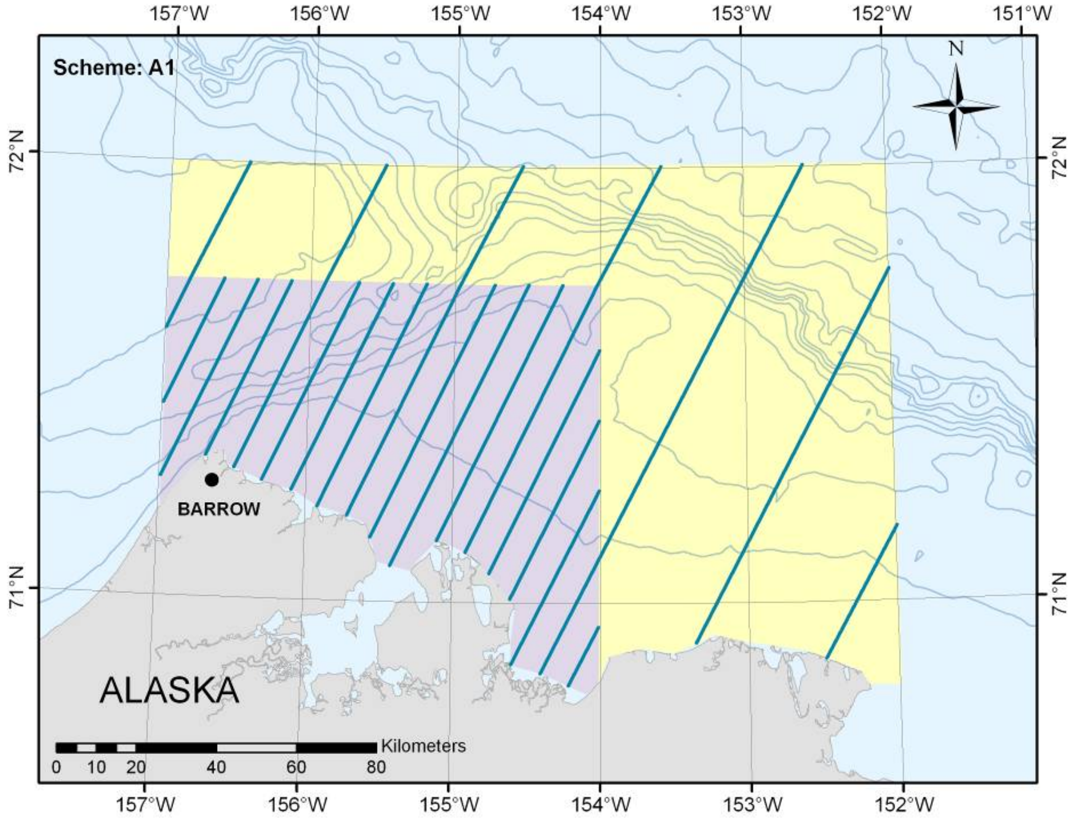

FIGURE 9.9. Two–part study area (smaller violet section and larger yellow section) for the aerial survey component of the 2007 BOWFEST program with proposed tracklines for the Aug portion of the survey.

Seven species of marine mammals were recorded during the aerial surveys (Table 9.3). All bowhead sightings were recorded on 23 and 24 Aug. This included 10 sightings of ~40 whales on 23 Aug and 6 sightings of ~9 whales on 24 Aug. Based on the multidirectional positioning of whales as well as the presence of mud plumes, most of the bowheads sighted appeared to be feeding. No bowhead whales appeared to be migrating through the area. Since the fall migration across the central Beaufort Sea typically begins in early Sep, the majority of whales (both feeding and migrating) were expected late in the field season. Instead, all bowhead sightings were recorded early in the season on 23–24 August during 11 hr of flight time, and no whales were seen during 20 hr of flight time on 6–11 September. Collecting additional years of data as well as integrating information with other projects will help elucidate whether bowheads feeding near Point Barrow in the summer and the apparent late migration observed in 2007 were typical or anomalous.

Since no bowhead whales were seen during the Sep portion of the survey, all bowhead photographs were taken 23–24 Aug. On 23 Aug, ~1.7 hours (295 km or 183 mi) were spent photographing bowhead whales. Within this time, 147 pictures (183 whale images) for photogrammetry (PGRAM) and 147 pictures (165 whale images) for photo identification (PID) were taken. On 24 Aug, 1.4 hours (243 km or 151 mi) were spent on photographic effort, including 0.94 hours used to photograph the calibration target (29 photographs) and 0.44 hours to photograph bowhead whales. On 24 Aug, 11 pictures were collected for photogrammetry (16 whale images) and 14 photos for photo–identification (16 whale images). Although there were 380 bowhead whales counted on a total of 319 photographs, the number of unique bowhead whales will most likely be less after accounting for duplicate images.

Passive Acoustic Monitoring

Six hydrophone packages which included temperature recorders were deployed offshore in the Beaufort Sea between Barrow and Cape Halkett in mid–Aug 2007. One hydrophone package located off Cape Halkett was recovered on 11 Sep 2007. Planned recovery of another package in shallow water near Barrow could not be completed due to advance of sea ice, and five hydrophone packages remained deployed through winter 2007–2008.

Sampling from the Cape Halkett package was continuous from 16 Aug to 11 Sep 2007. Bearded seal vocalizations and wave noise were identified but no calls that could definitely be attributed to bowhead whales were found during analysis. Water temperature increased from ~0.75 to 3.75ºC during the deployment period off Cape Halkett.

TABLE 9.3. Summary of sightings and numbers of marine mammals seen during aerial surveys in the BOWFEST study area in August and September 2007. Counts may include resightings between days.

Common Name	Scientific Name	Sightings	Count
Bowhead Whale	*Balaena mysticetus*	16	49
Beluga Whale	*Delphinapterus leucas*	17	29
Gray Whale	*Eschrichtius robustus*	20	29
Walrus	*Odobenus rosmarus*	65	255
Bearded Seal	*Erignathus barbatus*	32	90
Ringed Seal	*Phoca hispida*	73	119
Unidentified pinniped	—	10	12
Polar Bear	*Ursus maritimus*	1	1

Mooring and Broad–scale Oceanography

Shallow water moorings equipped with a CTD and acoustic current meter were deployed in Ekilukruak Entrance near Cooper Island and in Eluitkak Pass near Barrow to measure exchange between Elson Lagoon and the nearshore Beaufort Sea. Oceanographic sampling was conducted at 64 stations in offshore locations west, north, and east of Barrow. An Acrobat towed vehicle (temperature, salinity, chlorophyll and CDOM fluorescence, optical backscatter), and an acoustic Doppler current profiler were towed along most survey lines, weather permitting. Most of the data analyses are underway.

Other BOWFEST Study Components

Field studies were conducted in 2007 for two other components of the BOWFEST program including (1) Tagging and Fine–scale Oceanography, and (2) Bowhead Whale Harvest Sampling. Few whales were encountered during the Tagging and Fine–scale Oceanography component of the BOWFEST program and no results were obtainable in 2007.

The Bowhead Whale Harvest Sampling component of the BOWFEST program involved collection of stomach and tissue samples from bowhead whales harvested at Kaktovik in fall 2007. These samples are currently undergoing analyses.

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10. DISCUSSION, CONCLUSIONS, AND ASSESSMENT OF POTENTIAL EFFECTS OF SEISMIC ACTIVITIES ON MARINE MAMMALS IN THE CHUKCHI AND BEAUFORT SEAS[1]

INTRODUCTION

The dynamics of the physical environment in the Beaufort and Chukchi seas create high temporal and spatial variability in conditions that affect marine mammals. While the Chukchi Sea is relatively shallow and uniform in depth, the presence of currents and movements of sea ice alter the suitability of particular areas for marine mammals over variable time scales. Similar dynamic patterns occur in the Beaufort Sea although there the sea floor depth is much less uniform with deeper water occurring relatively close to shore where the continental shelf transitions to the Arctic Basin.

The extent and persistence of sea ice in the Chukchi and Beaufort seas have shown wide variability over the past decade and may be especially important for determining habitat use by walruses, polar bears, beluga whales, bowhead whales, ice seals, and other marine mammals. Sea–ice cover in the study areas differed markedly between 2006 and 2007. Average ice cover was almost four times greater in the Chukchi Sea and two times greater in the Beaufort Sea in 2006 compared to 2007. In general, a declining trend in the extent of arctic sea ice has occurred since 1953 and it reached a record low in 2007 (Stroeve et al. 2008). The change in ice cover from 2006 to 2007 was probably the major factor influencing the large difference in the numbers and distributions of walruses in the Chukchi Sea study area. Additionally, the two years differed with regard to the timing and distance off shore of the fall bowhead whale migration through the Beaufort Sea. This may also have been due, at least in part, to the differences in ice cover between the two years.

The spatial and temporal variability in the environment of the Chukchi and Beaufort seas drives large scale movements of many of the marine mammal species that inhabit these areas. These movements lead to wide seasonal variation in habitat use and marine mammal abundance, and to a large degree determine the timing and success of subsistence hunts of these resources by Native people in the area (George et al. 2004).

This high degree of variability in both the physical and biological aspects of the Chukchi and Beaufort seas makes it challenging to characterize and assess the patterns of marine mammal movement, behavior and abundance, and the potential effects of human activities on those patterns. This is particularly true when trying to recognize and distinguish longer term changes (or potential changes) in distribution, timing and abundance, effects of year–to–year changes in environmental variables like ice cover, and potential effects of human activities. Long–term trends and natural year–to–year fluctuations may influence patterns of marine mammal movement, behavior, and abundance at least as much as do the human activities whose potential effects are to be assessed.

There have been numerous studies of marine mammals in the Beaufort Sea over the past two to three decades focusing on bowhead whales, beluga whales, seals and polar bears. Industry research and monitoring programs have contributed to our understanding of impacts to marine mammals from oil and gas exploration and production and of year–to–year variation in distribution. Various government entities including the Minerals Management Service (MMS) and the U.S. Fish and Wildlife Service (USFWS) have also funded long–term research in the area. In the Chukchi Sea far fewer studies have been

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conducted and very few of those studies have been in recent years. Many of the data sets for the Chukchi Sea are 20 years old, or more, making the 2006 and 2007 data from this program important for improving the understanding of marine mammal use of the Chukchi Sea. The discussion and conclusions presented here for the Chukchi Sea should be viewed in the framework of this limited data set, which encompasses only two years of data collected across a large area in years with markedly different ice–cover conditions. Interpretation of broad patterns from such data is inherently limited.

MARINE MAMMAL MONITORING IN THE CHUKCHI SEA

The Joint Monitoring Program (JMP) was initiated by SOI, ConocoPhillips Alaska Inc. (CPAI), and GX Technology (GXT) in 2006. Vessel–based observations, aerial surveys, and acoustic techniques were used to collect data on the density and distribution of marine mammals in the Chukchi Sea from early Jul through mid–Nov in 2006. In 2007, vessel–based monitoring activities were continued from the operating seismic ship, chase/monitoring vessels, and various support vessels used during seismic operations by SOI. These observations generally occurred in a limited area as much of the seismic survey activity was located in relatively small blocks within the MMS Planning Area. In 2006, data were collected over a broader area of the Chukchi Sea in conjunction with somewhat wider ranging seismic surveys conducted that year by GX Technology (GXT) and via vessel–based surveys conducted as part of the JMP program within the MMS Planning Area. Ice cover was much more extensive in 2006 than in 2007 and limited the area that could be surveyed, particularly during Jul and early Aug.

Aerial surveys were conducted over nearshore waters and the coastline of the Chukchi Sea between Barrow and Pt. Hope at (approximately) biweekly intervals for most of the period from mid–Jul through mid–Nov in both 2006 and 2007. Surveys began shortly after the annual spring beluga whale hunt by the village of Pt. Lay. Logistical constraints near the end of Jul in 2006 prevented surveys from being flown from late Jul until late Aug of that year.

Acoustic studies were conducted along the Chukchi Sea coast and at additional locations in deeper water using bottom–founded recorders. During 2006 five recorders were deployed off each of Cape Lisburne, Pt. Lay, Wainwright, and Barrow. The five recorders in each area were deployed perpendicular to the coastline from ~6 to 58 mi (10 to 93 km) offshore, except near Barrow, where the recorders were positioned approximately parallel to the Chukchi Sea coast and extending beyond Pt. Barrow due to strong currents associated with Barrow canyon. These recorders provided information on the received sound levels from seismic survey activities at various distances from shore, as well as marine mammal vocalizations at those locations.

In 2006, the design of the aerial and acoustic studies and the impact of ice on the vessel–based surveys skewed the results of the studies toward nearshore locations and limited the number of data collected farther offshore in the MMS Chukchi Sea Planning Area. The vessel–based results from 2006 reflected both the areas where seismic work was occurring and the location of the pack ice during the early part of the season. In 2007, the acoustic studies were able to collect data on sound levels from seismic acquisition and on marine mammal vocalizations across a larger portion of the Chukchi Sea. The greatly reduced ice cover during 2007 did not restrict access of program vessels to particular portions of the study area as it had in 2006.

Cetaceans

There were relatively few reports of vessel–based observations of marine mammals in the Chukchi Sea prior to 2006. Brueggeman et al. (1992) summarized data that were collected from an icebreaker operating near drilling activities, with 43% of the observation effort occurring while the vessel was stationary. In 2006, data were collected from periods when vessels were underway, making direct comparison of observation data difficult. A small number of other marine mammal observations have been recorded during brief transits of the Chukchi Sea during the open–water season (Haley and Ireland 2006; Haley 2006), but the limited amount of time spent in the Chukchi Sea during these transits also makes comparison to the current results of marginal value.

In 2006, MMOs recorded a total of 79 useable cetacean sightings of 130 individuals in the Chukchi Sea. Bowhead whales, gray whales, and harbor porpoises were seen most frequently (25, 23, and 9 sightings, respectively). In a few cases, species uncommon to the area were documented, such as a fin whale sighting south of the project area on 23 Sep. Calls of fin whale were also recorded on bottom–founded hydrophones in the Chukchi Sea in 2006 (Chris Clark, pers. comm). In general, the species present were similar to those previously reported in the area (MMS 2007).

In 2007, 64 cetacean sightings of an estimated 110 individuals were recorded within the Chukchi Sea during vessel–based activities. The most commonly recorded cetacean species in 2007 was gray whale (32 sightings), followed by harbor porpoise (10 sightings), and bowhead whale (6 sightings). Two sightings of humpback whales, which normally do not occur in the Chukchi Sea, were also reported during the 2007 vessel–based activities (Chapter 3).

The species composition of cetacean sightings in 2007 was similar to that observed in 2006 with approximately 90% of useable observations in each year consisting of bowhead whales, gray whales, and harbor porpoises. The largest difference between years was in the percent composition of gray and bowhead whale sightings. Approximately 32% of useable Chukchi Sea cetacean sightings were bowhead whales in 2006 compared to 9% in 2007, while gray whale sightings comprised only 29% of useable observations in 2006 compared to 50% in 2007.

Compared to 2006, cetacean sighting rates in 2007 were higher in Jul–Aug and lower in Sep–Nov. Differences in the abundance and distribution of gray whales in Jul and Aug of the two years and in the timing of the bowhead whale migration into the Chukchi Sea, possibly influenced by their activities as they passed through the central and western Beaufort Sea, may have been responsible for the observed trends. This may have resulted from higher numbers of gray whales being present in the Chukchi Sea during their summer feeding period in Jul and Aug than were present in autumn. Most gray whales left the Chukchi Sea by mid–Sep in both years. The lower fall cetacean sighting rates in 2007 compared to 2006 may have resulted from a later arrival of bowheads in the Chukchi Sea in 2007. Bowhead whales observed during aerial surveys in the Beaufort Sea were commonly noted to be feeding well into Sep (Chapter 7) suggesting that the presence of greater food resources in the Alaskan Beaufort Sea in 2007 may have contributed to a later arrival of bowhead whales in the Chukchi Sea that year. Also supporting the suggestion of a late arrival of bowheads in the Chukchi Sea was that hunters from Barrow noted that although some bowheads were observed just east of Barrow in late August, few whales were seen there in mid–Sep when bowheads are typically quite common.

Gray Whales — Gray whales migrate north to the Chukchi Sea to feed, arriving in mid–Jun (Braham 1984; Moore et al. 1986; Moore 2000). Some gray whales continue east into the Beaufort Sea (Reeves et al. 2002; Angliss and Outlaw 2007), but most remain in the Chukchi Sea until Sep–Oct, when they migrate south to wintering areas in northern Mexico (Moore et al. 1986). Our survey results were generally consistent with these movements described in earlier studies.

Gray whale was the cetacean species most consistently sighted from seismic and support vessels combined and during aerial surveys in both 2006 and 2007; however, the distribution and abundance of this species were different in the two years. Based on aerial surveys, gray whales were 2.3 and 4.6 times more abundant in te survey areas during Jul and Aug of 2007, respectively, than during the same months in 2006. In 2006 gray whales were most abundant in Jul and declined during Aug and Sep; in 2007, their numbers peaked in Aug and then declined in Sep. Gray whale distribution within the survey area also was different between 2006 and 2007. In 2007, gray whales were most abundant in the northern part of the survey area from about Wainwright to Barrow. In 2006, they were most abundant in the central part of the survey area near Point Lay. Sighting rates were higher close inshore in 2006 and farther offshore in 2007; this was most likely due to a different distribution of their prey. Gray whale sighting rates in summer were similar during our 2006–07 study to those during a 1982–86 study (Moore et al. 2000); however, sighting rates were lower in autumn 2006–07 than during the earlier study.

Densities of gray whales, corrected for *f*(0) and *g*(0), in offshore areas during vessel–based surveys in summer 2006 (6.3/1000 km^2) were higher than summer 2007 (3.9/1000 km^2; Ireland et al. 2008), The opposite trend was reported during aerial surveys of the nearshore area (i.e., within ~37 km of shore) with higher gray whale densities in 2007 than 2006 (Chapter 4). This suggests that gray whale distribution may have been different in 2006 and 2007, with a shift in distribution from offshore areas in 2006 to nearshore areas in 2007. However, because of the small amount of vessel survey effort in offshore areas in 2007, the 2007 density estimates may not be reliable and it is possible that gray whales were not as abundant in the overall Chukchi Sea in 2006 as they were in 2007. Moore et al. (1986) observed inter–annual variability in gray whale abundance in the Chukchi Sea with peak abundance occurring in Jul during 1982, Aug during 1983, and Sep during 1984. Gray whales were sighted only once during late Oct in 2006 and no gray whales were sighted in Oct 2007. No gray whales were seen during Nov surveys in 2006 or 2007 and they were not expected to be present in the Chukchi Sea during winter, although Stafford et al. (2007) documented gray whales overwintering east of Barrow.

Gray whale use of nearshore habitats in 2006 was consistent with observations recorded during previous studies that documented gray whale use of coastal and shoal waters (Moore and DeMaster 1998; Moore et al. 2000). The northeastern–most of the known recurring feeding areas frequented by gray whales are located in the northeastern Chukchi Sea southwest of Barrow (Clarke et al. 1989). Gray whales routinely feed in the Chukchi Sea during summer and 73% of our combined aerial observations in 2006 and 2007 were of feeding animals. Moore et al. (2000) reported that gray whales summering in the Chukchi Sea clustered along the shore, primarily between Cape Lisburne and Point Barrow. In autumn, gray whales clustered near shore at Point Hope and between Icy Cape and Point Barrow, as well as in offshore waters northwest of Point Barrow at Hanna Shoal and southwest of Point Hope (Moore et al. 2000). Seismic survey activities and vessel operations generally occurred farther offshore and the reduced number of gray whale sightings from vessels during the mid– and late seasons compared to the early season was likely a result of vessel locations.

Bowhead Whales — The Bering–Chukchi–Beaufort (BCB) stock of bowhead whales migrates north from wintering areas in the Bering Sea through the Chukchi Sea in early spring (April–May) and arrives in summering areas in the eastern Beaufort Sea and Amundsen Gulf in Jun–Jul. Most of the bowhead whales that winter in the Bering Sea are thought to migrate to the Beaufort Sea during this period but a few may summer in the Chukchi Sea (see below). Bowhead whales return to the Chukchi Sea in the fall as they migrate back to the Bering Sea, in at least some cases via feeding grounds along the northeast coast of Chukotka (Sep–Nov; Moore and Reeves 1993; Quakenbush 2007). Observations from vessels in 2006 indicated that bowhead whales were most common in the Chukchi Sea during 25 Sep – 25 Oct (18 sightings, 25 individuals) although nearly as many whales were recorded during the earlier part of the season (9 sightings, 18 individuals). No bowheads were recorded from vessels from 26 Oct through mid–Nov 2006. In 2007, there were only six sightings of bowhead whales from vessels all in the later part of the season. Aerial surveys indicated that bowhead whales were most common in nearshore areas of the northern Chukchi Sea during Oct–Nov 2006 and 2007. Small numbers of bowheads were estimated to be in nearshore areas during Jul and Sep of 2006 but not in Jul or Sep of 2007. Bowheads were not seen during Aug of either year, but few surveys were conducted during Aug 2006. The relatively higher numbers of bowhead observations during the later part of the season likely resulted from the movement of bowhead whales through the Chukchi Sea during their fall migration.

Moore (1992) reported 26 sightings of bowhead whales during Jul and Aug in the northeastern Chukchi Sea from 1975 to 1991 and suggested that some bowhead whales may summer in the Chukchi Sea rather than moving into the Beaufort Sea. In 2006, bowhead whales were observed during aerial surveys in the Chukchi Sea during every month except Aug when few surveys were flown. Whether bowhead whales observed during Jul of 2006 remained in the Chukchi Sea for the entire summer is uncertain given the paucity of aerial surveys during Aug 2006. In 2007, no bowhead whale sightings were reported before Oct when whales would have been returning to the Chukchi Sea from the Beaufort Sea. However, hydrophones deployed off the Chukchi coast recorded bowhead whale calls throughout the open–water season of 2007 (chapter 5) and researchers from the *Oshoro Maru* 2007 summer cruise in the Bering and Chukchi seas reported an aggregation of 30 bowhead whales approximately 130 km (80 mi) north of Cape Lisburne on 9 Aug (Sekiguchi et al. 2008).

Acoustic recorders placed along the Chukchi Sea coast detected bowhead whale vocalizations in 2006 and 2007. Bowhead whales were recorded in fall 2006 by the arrays at Barrow, Wainwright, and Pt. Lay, but not at Cape Lisburne where the three recorders farthest offshore were not recovered. Detections decreased from Pt. Barrow to Pt. Lay, and a shift in detections relative to the coast occurred from Wainwright, where there were similar numbers of detections at various distances from shore, to Pt. Lay, where there were mostly inshore detections. In 2007, bowheads were recorded in the nearshore Chukchi Sea during summer.

Aerial and vessel survey data from 2006 and 2007 indicated an increase in bowhead whale abundance during the fall, as would be expected based on the known migration pattern. However, aerial survey data indicated that peak bowhead whale abundance in the study area occurred in Nov 2006 and Oct 2007, with most sightings in the Pt. Franklin area. Previous ship–based surveys in Sep and Oct of 1992 and 1993 did not record any bowhead sightings along the western coast of Alaska between Point Hope and Barrow (Moore et al. 1995). Recent satellite tagging data confirm earlier aerial–survey evidence that at least some bowhead whales continue their westward migration across the northern Chukchi Sea to waters near the Russian coast before migrating southeast toward and through the Bering Strait (Mate et al. 2000; Quakenbush 2007; Fig. 10.1). A reduction in call detections at the acoustical arrays from Barrow to Pt. Lay in 2006 suggested a possible dispersal of bowheads as they migrated through the Chukchi Sea. There was some indication in 2007 that more whales were located nearshore and farther offshore than in the mid–distances offshore, 65–93 km (40–58 mi).

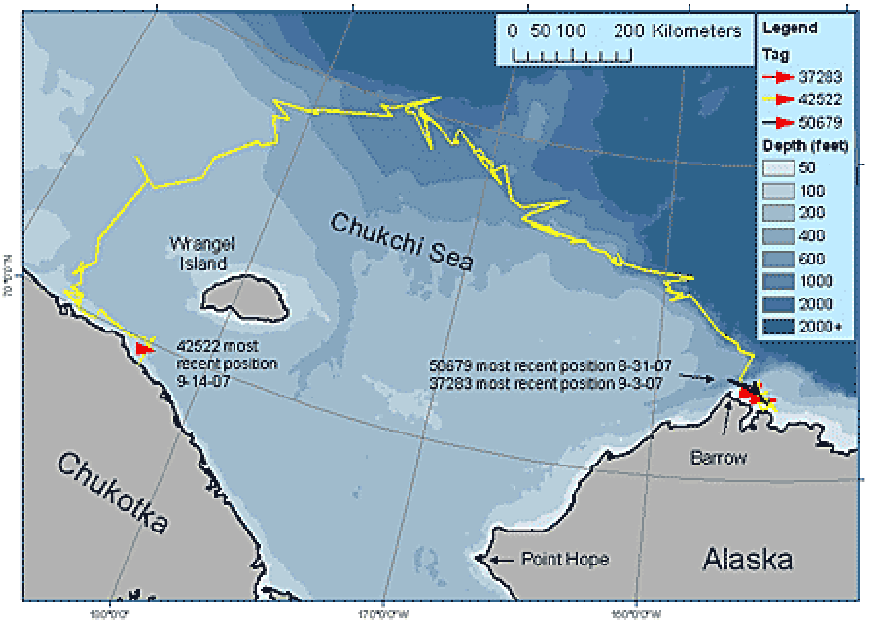

FIGURE 10.1. Bowhead locations 29 Aug to 14 Sep 2007 from satellite telemetry. All three whales were tagged on 29 Aug. Data are from a continuation of the study by Quakenbush (2007) and are available online at http://www.wildlife.alaska.gov/index.cfm?adfg=marinemammals.bowhead.

Beluga Whales — Two beluga whale populations are seasonally present in the Chukchi Sea. The Chukchi population spends part of the summer in the Chukchi Sea and the Beaufort population migrates through the Chukchi Sea during spring and fall. During Jun and Jul, Chukchi Sea beluga whales typically congregate in lagoons and nearshore waters along the Chukchi Sea coast, especially Omalik and Kasegaluk Lagoons near Point Lay (Huntington et al. 1999; Suydam et al. 2001). Some beluga whales have been reported migrating along the Chukchi coast in Apr and May (Moore et al. 1993) and movements past Barrow continue into Jun. Most of these migrating belugas are thought to move north to or into the pack ice and continue into the Canadian Beaufort Sea and Amundsen Gulf where they spend the summer (Suydam et al. 2001). Beluga whale sighting rates during aerial surveys were greatest during Jul (2006) and Aug (2007). Sightings decreased during mid–season and then increased later in the year, which was consistent with earlier studies (Suydam et al. 2001, 2005a). In 2006, beluga whale sighting rates and numbers of individuals were highest during the early season in coastal areas (within 5 km of shore). However, acoustic recorders deployed along the coast detected only five groups of beluga whales during 285 recorder–days from mid–Jul to late Aug. Beluga whale sighting rates were lowest in Aug and thereafter steadily increased through Nov with most whales recorded farther offshore during the mid– and late seasons. In 2007, sighting rates were lowest in Sep rather than Aug, perhaps because of the reduced ice cover in 2007. Detections of beluga whale calls on acoustic recorders in 2007 were sparse with only small numbers of calls recorded early in the season. Detections were only made along the Barrow and Wainwright recorder lines and call detection rates were approximately uniform with respect to distance from shore. Beluga whales were not reported by vessel–based MMOs in either 2006 or 2007.

Seals

Seal detection rates from vessels were lower in 2007 than in 2006. In 2006, the data showed an expected relationship of greater seal detection rates in areas closer to pack ice. The lower overall seal detection rate in 2007 may have been due, in part, to decreased ice cover in areas where vessels were operating. Bearded, ringed, and spotted seals were sighted throughout the survey area both from vessels and from aircraft. Sightings of seals peaked in Aug of both 2006 and 2007, but seals were sighted throughout the study period. Bearded seals were also sighted during all months of the study, but the greatest number of sightings occurred in Oct and Nov of 2007 and in Sep of 2006.

Seal densities calculated from vessel–based observations ranged from 69.7 to 485 seals/1000 km^2 (386 mi^2) in 2006 and 53.9 to 145.3seals/1000 km^2 (386 mi^2) in 2007. Densities reported for ringed and bearded seals by Bengtson et al. (2005), based on aerial surveys in the eastern Chukchi Sea, ranged from 70 to140 bearded seals/1000km^2 (386 mi^2), and 1620 to 1910 ringed seals/1000km^2 (386 mi^2). No correction factor was applied to the bearded seal densities and actual bearded seal densities may be greater than those reported by Bengtson et al. (2005). The Bengtson et al. (2005) aerial surveys were conducted earlier in the year (May/June) than the current surveys, primarily over pack ice, and cannot be considered equivalent to the current vessel–based surveys. No densities were derived from our aerial surveys because the survey altitude (optimized for whales) made detection of seals difficult and limited accurate identification of seals.

In 2007, seal detection rates were generally greater from support vessels than source vessels, and the difference was greater during seismic than during non–seismic periods. The same trend of increased detection rates by support vessels during seismic periods was found in 2006 suggesting possible localized seal avoidance of the seismic activities. However, no clear trend indicating avoidance was found when detection rates were compared for distances corresponding to 10–dB increments of received pulse level. A reaction behavior was recorded for ~30% of seal sightings from source vessels during seismic periods and for ~20% of sightings during non–seismic periods suggesting somewhat greater levels of disturbance during seismic periods.

Walrus

Most Pacific walruses winter in the southern Bering Sea and migrate north in the summer into the Chukchi Sea following the receding pack ice. Once in the Chukchi Sea, they spend the summer on the Alaskan side between 70° N and Barrow and on the Russian side between the Bering Strait and Wrangel Island. When ice is present near feeding areas they alternate periods of hauling out on ice pans with periods of feeding. Walruses feed primarily on benthic invertebrates and the ice edge provides them with a platform for resting adjacent to feeding habitat. Pacific walruses probably feed in relatively shallow water to ~80 m (262 ft) in depth although deeper dives have been recorded (Fay and Burns 1988). Most of the Chukchi Sea is relatively shallow with depths generally <50 m (164 ft) providing extensive feeding habitat. In Oct, the pack ice develops rapidly in the Chukchi Sea, and large herds begin to move southward.

Our 2006 survey results were consistent with these typical movements, but the observed distribution in 2007 was much different. During 2006, peak walrus sighting rates were in Jul in nearshore areas closely associated with the pack ice. Sighting rates in these nearshore areas declined markedly during Aug and Sep as the pack ice retreated. Presumably walruses remained with the pack ice that was present over shallow offshore waters. In contrast, during 2007 the pack ice retreated so far north early in the season that walruses appear to have abandoned the pack ice by late Aug. Pacific walrus sightings (n = 143) recorded from the source vessel *Gilavar* during a non–seismic period on 24 Aug before seismic activity began contributed 72% of the non–seismic sightings in 2007. These walrus sightings were in open water over 100 km (62.1 mi) from the pack ice. Later in Aug and early Sep large numbers of walruses were hauled out along the Alaskan Chukchi coast from Barrow to Cape Lisburne (Fig. 10.2). Walrus numbers at the Chukchi Sea haulouts ranged from ~100 to well over 1000 animals though precise counts are not yet available (Fig. 10.3). Walrus vocalizations were detected by bottom–founded recorders deployed in the Chukchi Sea throughout the study period with noticeable movements of animals into and away from shore. In particular, a noticeable movement from offshore to onshore was recorded along the Point Lay line of recorders in late Aug, although offshore vocalization activity continued throughout the season.

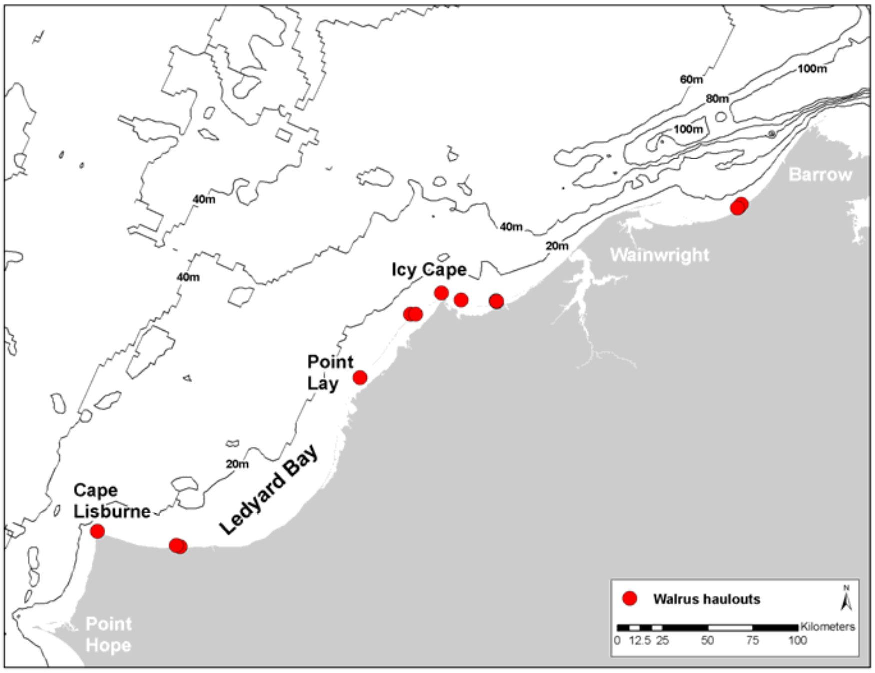

FIGURE 10.2. Pacific walrus haulouts recorded during aerial surveys along the Chukchi Sea coast 2007.

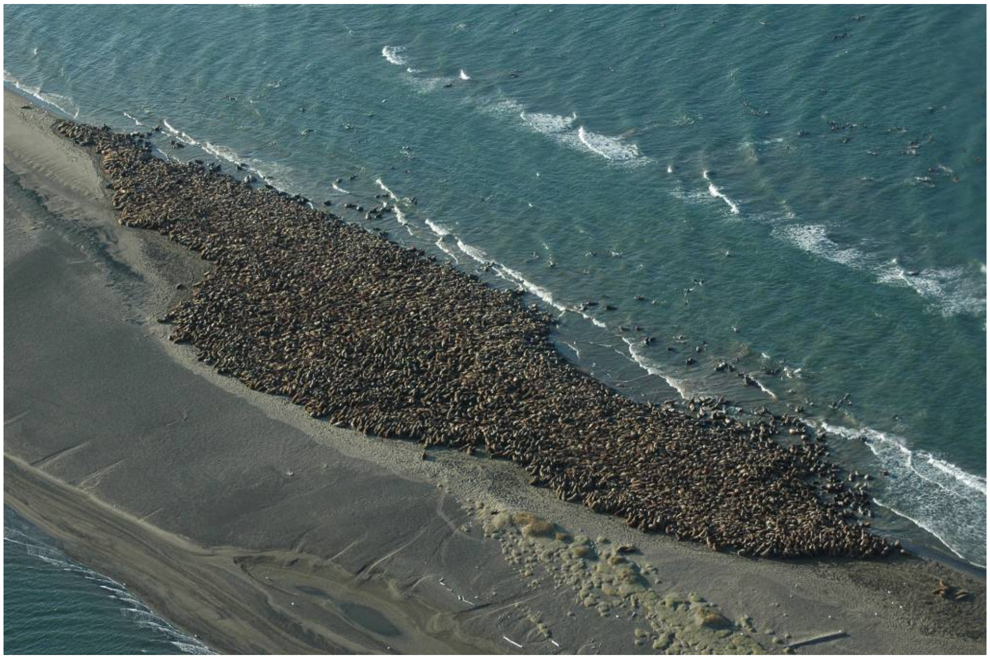

FIGURE 10.3. Pacific walrus haulout along the Chukchi Sea coast east of Icy Cape, 18 Sep 2007.

Pacific walruses normally haul out on ice to rest during the summer in the Chukchi Sea and generally do not haul out on land in large numbers along the Chukchi Sea coast. The use of terrestrial haulouts by walrus is common on the Chukotsk coast (Belikov et al. 1996), but is less common on the Alaska side of the Chukchi Sea. We suspect that in 2007 the pack ice retreated to water too deep for walrus feeding and that the use of land–based haulouts along the Chukchi Sea coast was an effect of the record low extent of Arctic sea ice reported for 2007. The large number of different sites used by large numbers of walruses on the Alaskan side has not been documented before, but it may become more common if the trend for reduced ice cover in the Chukchi Sea in summer continues. How the use of land–based haulouts along the Chukchi Sea coast rather than haulout locations on the pack ice will impact walruses is unknown. Cooper et al. (2006) reported at least nine Pacific walrus calves separated from adult females in waters as deep as 3000 m (1.86 mi) in Jul and Aug of 2004 in the Canada Basin of the Arctic Ocean, presumably due to the rapid seasonal sea–ice retreat during that year. The authors speculated that walruses may be ill adapted to such rapid retreat of sea–ice.

Polar Bears

Five sightings of polar bears (4 useable and 1 non–useable) were reported from vessels operating in loose pack ice, all during non–seismic periods (i.e., during periods uninfluenced by seismic activities) in 2006. No polar bears were reported from vessel surveys in 2007. No polar bears were reported during aerial surveys along the Chukchi Sea coast and over nearshore waters in either 2006 or 2007.

Polar bears occur in most ice covered marine waters of the Northern Hemisphere including the coastal waters of the Bering, Chukchi, and Beaufort seas. Over most of their range their distribution is primarily limited to locations near sea ice. Sea ice disappears from most of the Chukchi Sea during summer and polar bears migrate north with the drifting pack ice (Garner et al. 1990, 1994; Amstrup 2000). Therefore the low numbers of polar bears seen during the surveys in the Chukchi Sea were not surprising particularly in 2007 when the extent of Arctic sea ice reached a record low (Stroeve et al. 2008).

MARINE MAMMAL MONITORING IN THE BEAUFORT SEA

Sea ice was more concentrated in some nearshore areas of the Beaufort Sea in 2006 compared to 2007, which resulted in different levels of seismic survey activity during the two years. In 2006, sea–ice conditions in the area of SOI's prospects precluded deep seismic exploration and only shallow hazards and site clearance activities were conducted in the Beaufort Sea in 2006 by SOI. In Sep 2007, low ice cover in these same areas allowed SOI to conduct deep seismic exploration and to continue shallow hazards survey work. Deep seismic exploration was conducted from the source vessel *Gilavar* from 18 Sep through 3 Oct. Shallow hazards surveys were conducted in the Beaufort Sea from early Aug through early Oct in 2006, and from late Aug through early Oct in 2007. This work was done on an intermittent basis as allowed by ice and weather conditions. In addition to the vessel–based marine mammal observations in the Beaufort Sea in 2006 and 2007 (described in Chapter 6), SOI conducted aerial surveys as part of its monitoring and mitigation program during both years (Chapter 7). In 2006, SOI funded development of improved directional acoustic recorders for monitoring marine mammal calls and other sounds in offshore areas of the Beaufort Sea. During that program, background information on call distributions and sounds was collected in offshore areas that had not been monitored acoustically during earlier studies. In 2007, SOI used recorders that had been tested in 2006 to conduct a large–scale underwater acoustic monitoring program. This program was designed to provide information on fall migration paths of bowhead whales along the Alaskan Beaufort Sea coast in relation to SOI's 2007 exploratory activities (Chapter 8).

The aerial survey program was designed to provide information on the distribution and movements of marine mammals, particularly bowhead whales. Of particular interest was how far west of seismic operations bowheads would be deflected from their natural migration paths and at what distance beyond the seismic activities the migration corridor would return to normal. The initial survey routes were designed to collect information on whale distribution west of industry operations in addition to distribution near and east of the operations. The program was also designed to provide information needed for mitigation through monitoring the surveyed area for bowhead cow/calf pairs. Because sound source verification tests showed that seismic survey sounds traveled farther than initial models had predicted, aerial surveys in 2007 had to extend farther east than initially planned in order to monitor the ≥120 dB zone for bowhead cow/calf pairs. This meant that the 2007 surveys could not extend as far to the west as originally planned unless the spacing between the lines was increased. Therefore, survey lines were spaced farther apart with a lower overall percent coverage of the survey area. The aerial survey program in the Beaufort Sea was expanded in 2007 compared to 2006 due to the expanded scope of the 2007 exploration program—in particular, the operations of the *Gilavar*. In 2006, surveys were flown from late Aug through late Sep in the Camden Bay area in support of shallow hazards surveys. In 2007, the survey area was expanded to both the west and the east, and extended from Harrison Bay to Kaktovik. In 2007, aerial surveys were conducted from late Aug through early Oct in support of both shallow hazards and deep seismic surveys.

The acoustic study was initiated by SOI on ~20 Aug 2007 and continued until 12 Oct, with a few recorders left in the water to collect acoustic data throughout the fall, winter, and spring. The latter recorders will be retrieved in summer 2008. Five arrays each consisting of seven Directional Autonomous Seafloor Recorders (DASARs) were deployed at locations along the Beaufort Sea coast from eastern Harrison Bay to Kaktovik (Chapter 8, Fig. 8.3). The southernmost DASARs of each array were located 15–33 km (9–21 mi) offshore with the remaining DASARs in each array extending northward to 21 km (13 mi) from the southernmost DASAR.

Cetaceans

Numerous aerial surveys to determine the distribution of marine mammals, particularly bowhead and beluga whales, have been flown over the Beaufort Sea since the late 1970s (e.g., Davis et al. 1985; Moore et al. 1993, 2000; Moore and DeMaster 1998; Miller et al. 1999; Monnett and Treacy 2005). However, few systematic vessel–based studies of marine mammals have been reported in offshore areas of the Beaufort Sea. Richardson and Lawson (2002) reported on marine mammals observations made during Ocean Bottom Cable (OBC) seismic surveys in the Beaufort Sea from 1996 to 2001. These surveys were generally in relatively nearshore areas inside or just outside the barrier islands and the majority occurred during mid– to late summer prior to the peak of the bowhead whale migration. Consequently, and possibly due to the tendency for cetaceans to avoid approaching seismic vessels, most of the marine mammals observed were seals. Miller et al. (1998) reported one vessel–based bowhead whale sighting during OBC surveys in relatively nearshore areas between Northstar and Flaxman islands in 1996 and 1997.

***Gray whales* —** Gray whales are much less abundant in the Beaufort Sea than in the Chukchi Sea. The Beaufort Sea is outside of their normal range and in the 1970s to mid–1990s gray whales were rarely seen in the Beaufort Sea (Rugh and Fraker 1981; Miller et al. 1999). Starting in the late 1990s, small numbers of gray whale sightings were recorded in most years. Reasons for increases in sightings are unknown, but may include extension of their range as the population recovered and declining sea ice in the Arctic. During vessel–based observations in the Beaufort Sea in support of the current seismic and shallow hazards surveys, only two gray whale sightings of three individuals were recorded in 2006 and one sighting of one individual in 2007. Similarly, few gray whales were sighted in the Beaufort Sea during aerial surveys in 2006 or 2007. Three and one gray whale sighting were recorded in 2006 and 2007, respectively; however, only one of the four sightings was made during useable sighting conditions. The numbers of gray whale sightings were too low to perform any analyses of distribution, habitat use, or of the potential effects of activities in the Beaufort Sea on gray whales. Gray whale sightings have tended to be near the coast and few gray whales were likely to have been affected by seismic operations in the Beaufort Sea in 2007 or site clearance surveys in 2006 and 2007.

Beluga whales — The westward migration of beluga whales through the Alaskan Beaufort Sea typically begins in Aug and continues through Oct (Moore and Reeves 1993). The main beluga migration occurs near and north of the edge of the pack ice and the continental slope, although a few animals are seen closer to the coastline. Beluga whales were not sighted by vessel–based MMOs in the Beaufort Sea in either 2006 or 2007, but sightings were made during aerial surveys in both years (Chapter 7). Sighting rates and number of individuals seen were higher in 2006 than 2007 although the differences where not statistically significant. Peak beluga whale sighting rates occurred in early Sep when data from the two years were pooled. Past studies have reported peak beluga abundance in the central Alaskan Beaufort Sea in early–Oct (Miller et al. 1999).

Beluga whale sighting rates based on the combined 2006–2007 data were highest in the band 90–95 km (56–60 mi) offshore but sighting rates were also relatively high as close as ~60 km (37 mi) from the coast. Few belugas were recorded closer than 55–60 km (34–37 mi) from shore. As in past studies (Miller et al. 1999; Moore et al. 2000), beluga whales were generally found farther offshore than bowhead whales. Similar results were seen in the 2006 SNACS survey area near Barrow (Appendix G in Funk et al. 2007) where most beluga whale sightings (n = 219; 75%) occurred at distances >50 km from shore. Only 73 beluga whales in the SNACS study were documented within 50 km of shore. Beluga whales were typically observed in water ≥100 m (≥305 ft) deep, although they were occasionally observed inshore of the 50 m isobath (Chaper 7).

Bowhead whales —The majority of the BCB stock of bowhead whales migrates eastward through the central Alaskan Beaufort Sea in spring (April to mid–June), and arrives in summering areas in the Canadian Beaufort Sea and Amundsen Gulf in May–July. A few bowheads may remain in the northeastern Chukchi Sea during summer (Moore 1992) and little is known about their distribution and movements during summer and early autumn. Most bowheads that summer in Canadian waters do not return to the Alaskan Beaufort Sea until fall (late Aug to late Oct or possibly later; Moore and Reeves 1993; Miller et al. 2002).

Three cetacean sightings were recorded during vessel–based surveys in the Beaufort Sea in 2006 compared to 32 cetacean sightings in 2007, the majority of which were bowhead whales. The overall amount of useable effort was slightly greater in 2007 which may have accounted for part of the difference in the sighting numbers. However, aerial survey data suggest that bowhead activities were much different in the prospect areas in 2006 and 2007, and this likely influenced the numbers sighted in each year.

No bowhead whales were sighted from vessels in the Beaufort Sea in 2006, but in 2007, 20 bowhead sightings of 51 individuals were recorded during vessel–based observations. Most of these sightings (15) were recorded by MMOs on support vessels, probably related in part to the higher amount of effort from support vessels compared to source vessels in 2007.

In contrast to the vessel–based surveys, bowheads were commonly observed during aerial surveys in both 2006 and 2007 (Chapter 7). Bowheads were observed during 89 and 88% of the aerial surveys during 26 Aug through 24 Sep in 2006 and 2007, respectively. The last aerial survey in 2006 occurred on 24 Sep, but in 2007 aerial surveys continued through 8 Oct. The numbers of bowhead sightings decreased during this later survey period in 2007 and bowhead sightings were recorded on only 33% (two of six) of surveys from 26 Sep through 8 Oct. The overall average group size was 1.5 bowheads per group in each year. When data from the two years were combined sighting rates peaked in early Sep with a smaller peak during the latter part of Sep. Blackwell et al. (2008) reported two early–season peaks in bowhead call detection rates near Northstar Island in 2007, one in late Aug and one around 7 Sep. with a third peak around 15–21 Sep. Bowhead whales were present in the Camden Bay area on eight of nine surveys during the 2006 aerial survey period of 26 Aug–24 Sep, and on most surveys from 22 Aug through the end of Sep 2007.

Peak bowhead migration near Kaktovik, at least in years up to 2000, was usually around 18 Sep (Fig. 10.4) with the majority of whales passing Kaktovik from about 3 to 25 Sep (Miller et al. 2002). Whale behaviors recorded during aerial surveys in 2007 suggest that whales in our survey areas during late Aug to mid–Sep were feeding and may have interrupted their westward migration to remain in the area. However, some bowheads from Canada may have migrated through our survey area before aerial surveys started. Green et al. (2007) reported early sightings of bowhead whales in mid–Aug 2007 east of Barrow near Smith Bay, and bowheads were reported northeast of Barrow on 23 and 24 Aug 2007 by Goetz et al. (2008). Whether these bowhead were early migrants or whales that may have summered in the Beaufort or Chukchi seas is unknown.

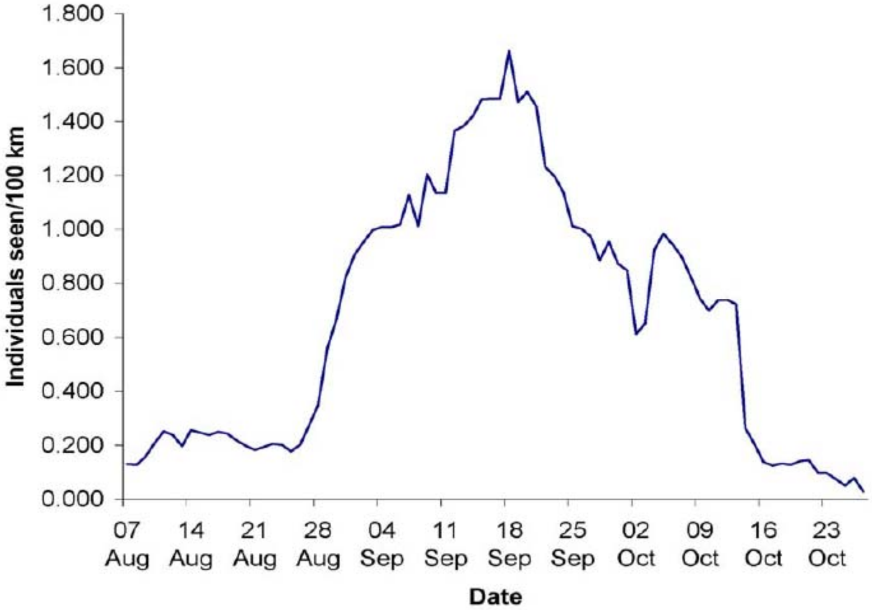

FIGURE 10.4. Plot of 10–day moving average of bowhead abundance (individuals seen/100 km) during aerial surveys in the eastern Alaskan Beaufort Sea, 7 Aug.–27 Oct., 1979–2000. The study area extended from Flaxman Island to the Canadian border (from Miller et al. 2002).

Bowhead sighting rates during aerial surveys were greatest in the 15–20 km (9–12 mi) offshore band in 2007 and ~60 km offshore in 2006. The 2006–2007 differences in sighting rates with distance from shore between the two years may be due to differences in ice conditions. Bowhead whale distribution in the Alaskan Beaufort Sea during late summer and autumn has been shown to vary with ice conditions (Moore 2000; Treacy et al. 2006). Bowhead whales tend to occur farther offshore in years of heavy ice (95% CL: 67.2–79.6 km [41.8–49.5 mi]) compared to years of moderate (95% CL: 44.8–53.8

km [27.8–33.4 mi]), or light (95% CL: 30.0–32.4 km [18.6–20.1 mi]) ice conditions (Treacy et al. 2006). The sighting distributions in 2007 and 2006 were consistent with what would be expected in a low and moderate ice year, respectively.

BP Exploration (Alaska) Inc. has conducted acoustical studies annually to monitor the bowhead whale migration past Northstar Island since 2001 (Blackwell et al. 2008). A comparison of the bearings to calling whales in 2007 indicated a similar distribution to that of previous low–ice years. Ice concentration was greater in the Northstar area in 2005 and 2006, and higher bowhead calling rates in 2007 were likely related to the absence of nearshore pack ice, and to the occurrence of bowheads closer to shore in 2007. Laurinolli et al. (2008) reported calls of bowhead whales from a bottom–founded hydro–phone located near Thetis Island in eastern Harrison Bay from 18–23 Sep 2007. The bowhead calls could not be localized and the precise location of the whales was unknown. However, these data provided further evidence that at least some bowheads may have been migrating through nearshore areas in 2007.

Bowhead whales feed extensively in the Canadian Beaufort Sea during the summer and then continue to feed intermittently during fall migration across the Alaskan Beaufort Sea (Landino et al. 1994; Miller et al. 1999, 2002; Würsig et al. 2002; Lowry et al 2004). Recurrent bowhead whale feeding areas have been identified near Kaktovik and northeast of Barrow, where whales have been observed feeding during the fall. Some whales also feed near Cross Island in the Prudhoe Bay area (Lowry et al. 2004). Behavioral and movement data collected during aerial surveys in 2007 indicated that more feeding occurred in the Alaskan Beaufort Sea than has been observed during most previous years (Chapter 7). Bowhead feeding was one of the main activities recorded during the 2007 aerial surveys.

Seals, Walruses, and Polar Bears

During seasonal periods with sufficient effort to meet usability criteria for sightings data, seal detection rates ranged from 22.4 to 134.0 seals/1000km (621 mi) for the combined 2006 and 2007 vessel–based observations (Chapter 6). Ringed/spotted seals were recorded far more frequently than bearded seals by both vessel–based observers and during aerial surveys. No seasonal patterns in seal detection rates were obvious. The highest seal detection rate was reported during fall 2006 from the source vessel (*Henry C.*). Seasonal detection rates from source vessels in 2007 were similar and ranged from 45.9 to 63.7 seals/1000km (621 mi). Seal detection rates from support vessels were ~4 times higher in summer (91.4 seals/1000km^2 [386 mi^2]) than fall (22.4 seals/1000km^2 [386 mi^2]) 2007. Useable effort from support vessels in 2006 was too low to make any comparisons of seal detection rates by season. Some seasonal differences in seal detection rates may have been due to differences in ice conditions in 2006 and 2007.

Overall seal density calculated from vessel–based observations in 2006 was 358 seals/1000 km^2 (386 mi^2). In 2007 seal densities during vessel–based observations ranged from 168.1 to 431.6 seals/1000 km^2 in the fall and summer, respectively. Seal densities during other vessel–based observations in the Beaufort Sea ranged from 51 to 300 seals/1000 km^2 (386 mi^2; Harris et al. 1997, 1998; Moulton and Lawson 2000, 2002). Moulton et al. (2002) reported seal densities in the Beaufort Sea near Northstar Island ranging form 490 to 630 seals/1000 km^2 (386 mi^2). However, these densities were based on spring aerial survey data of seals hauled out on landfast ice and may not be comparable to densities based on vessel–based observations. Frost and Lowry (1999) reported higher densities ranging from 1010 to 2940 seals/1000km^2 (386 mi^2) during similar spring aerial surveys in the Beaufort Sea. No densities were derived from our aerial surveys because the surveys were conducted primarily over water at altitudes too high to make consistent observations of seals.

Pacific walruses are uncommon in the Beaufort Sea. No Pacific walruses were recorded during vessel–based activities in 2006 and only five sightings of nine individual walruses were recorded in 2007.

Five sightings of Pacific walrus were recorded during the aerial surveys in 2006, but no walruses were observed during aerial surveys in 2007. Ice was more prevalent in the survey area in 2006 than 2007 which may help to account for the 2006 aerial sightings, but does not explain the lack of vessel–based sightings in 2006. The numbers of sightings of Pacific walruses from vessels and during aerial surveys are too low to draw meaningful conclusions regarding seasonal distribution and densities of walruses in the Beaufort Sea.

More polar bear observations were recorded in the Beaufort Sea during vessel–based activities in 2007 (eight sightings of 14 individuals) than 2006 (three sightings of four individuals). Polar bears were also more frequently recorded during aerial surveys in 2007 (27 sightings of 47 individuals) than in 2006 when only one polar bear was observed. The higher numbers of polar bear sightings during aerial surveys in 2007 were likely a result of survey effort and location. Survey effort was reduced in 2006 and surveys were confined to the Camden Bay area where there are no barrier islands. The survey effort in 2007 was greater than in 2006 and many of the areas surveyed included barrier islands where polar bears are known to occur.

POTENTIAL INTERACTIONS OF INDUSTRY AND OTHER HUMAN ACTIVITY IN THE CHUKCHI AND BEAUFORT SEAS

Chukchi Sea

Industry activities in the Chukchi Sea during the open–water period in 2007 were primarily associated with the seismic operations conducted by SOI in the MMS Planning Area. In addition to the seismic program, some barges, research vessels, and various small boats were also operating during summer and fall.

Seismic Operations — The *Gilavar* left Dutch Harbor on 18 Jul to travel to the project area and entered the Chukchi Sea on 21 Jul. Operations were then delayed while SOI waited for final approval of the IHA, which was issued on 20 Aug. SOI's seismic contractor (WesternGeco) deployed the seismic acquisition equipment and sound source measurements of the airgun array were performed by JASCO on 28 and 29 Aug during 9 hr of seismic shooting. JASCO calculated preliminary disturbance and safety radii within 72 hr of completion of the measurements. The *Gilavar* collected seismic data in the Chukchi Sea from 28 Aug through 10 Sep. The *Gilavar* left the Chukchi Sea on 12 Sep to conduct seismic surveys in the Beaufort Sea. The *Gilavar* returned to the Chukchi Sea on 8 Oct initially transiting to Nome. After returning from Nome, additional seismic acquisition in the Chukchi Sea began on 20 Oct and continued through 5 Nov when adverse weather conditions ended further exploration activities. SOI was the only operator conducting an active seismic program in the U.S. portion of the Chukchi Sea in 2007, although JASCO reported detecting distant seismic pulses on their Barrow recorders from 19 Aug to 8 Oct, and recorders near Pt. Lay detected 3 minutes of airgun activity on 8 Aug before the SOI program began.

The seismic surveys occurred in the MMS Chukchi Sea Planning Area. All seismic acquisition in the Chukchi Sea occurred more than 50 miles from the Alaska coast in OCS waters averaging greater than 40 m (131 ft) depth and outside the polynya zone.

From 29 Aug to 10 Sep, sounds associated with seismic surveying were recorded on bottom–founded acoustic recorders deployed near Point Lay, Wainwright, and Cape Lisburne. During that time the SPLs for all stations except PLN40, which was well offshore and nearest the seismic survey activity, were generally below 115 dB re 1μPa (rms). Recorders deployed in 2006 documented pulses with received levels as high as ~130 dB re 1 μPa (rms) during active seismic periods. During some periods in 2006, two seismic ships were working simultaneously in the Chukchi Sea.

The SPL over time on the offshore station PLN40 (located ~61 km or 38 mi from the center of the seismic survey area showed a clear increasing and decreasing pattern that was most likely due to the progress of the survey vessel as it moved closer to and farther from the recorder. Other discontinuities in the SPL were likely due to transitions from the full array to a single mitigation gun during power downs or survey line changes. Over a 32 minute period, average SPLs during the survey ranged from 100 to 137.4 dB re 1µPa (rms) on this single recorder. Individual shots often reached 142 dB re 1µPa, and on two occasions exceeded 144 dB re 1µPa (rms).

During the second survey period (20 through 26 Oct), the airgun sounds were detected on recorders near Wainwright and Barrow (W35R, W50R, B35R and B50R stations). At the W50R OBH (located ~58 km or 36 mi from the center of the seismic survey area), over a 32–minute period average shot SPLs were as high as 132 dB re 1 µPa, and individual shots typically peaked at ~138 dB re 1 µPa (rms).

Ambient sound levels in 2006 off Cape Lisburne, Point Hope, and Wainwright recorded at the #2 recorder in each array ranged between ~90 and 100 dB re 1 µPa whereas levels of ambient sounds averaged several dB higher at the #5 recorder. In 2007, ambient sounds were highly variable, as they were in 2006, but generally ranged from ~85 to 125 dB depending upon the location of the recorder and weather conditions at the time of the measurements.

The seismic vessels in 2006 were generally closer to the "offshore" recorders than to the nearshore recorders, and the higher ambient levels recorded at the #5 recorders may, to some degree, have resulted from the contribution of routine vessel noise to the recordings in offshore waters and some reverberation of the seismic pulses. However, the main noise sources offshore were related to ice and wave action. In 2007, this was also generally true. JASCO reported high ambient sound levels at several of their nearshore recorders, but were unable to identify the source(s) of these higher levels of low frequency sound.

***Vessel Traffic* —** In addition to the seismic vessels operating in the Chukchi Sea, various other vessels supported the seismic operations. In general, these included the chase/monitoring boats associated with the seismic vessel (usually the *Gulf Provider* and the *Norseman II, Nanuq,* or *American Islander*), and a crew change boat (the *Peregrine*).

Sound levels from each support vessel used by SOI were measured. While the source levels of the routine vessel operations do not approach the source levels produced by the seismic airgun arrays at times when pulses are being received, these smaller vessels may produce a substantial amount of sound, particularly if a number of vessels are operating in a relatively small area such as a harbor or bay. Also, vessels produce continuous sound whereas an airgun array produces sound for only a fraction of a second every several seconds (i.e., duty cycle 100% vs. <5%). Sounds from all of these vessels contributed to the total in–water sounds. A wide variety of shipping and boating sounds was reported throughout the 2007 study period from recorders deployed in the Chukchi Sea. The SPLs for vessel sounds were reported as generally being above the 95th percentile of ambient sound levels, but they never exceeded 120 dB re 1 µPa at the recorder.

Using tonal peaks as indicators of shipping noise it was possible to account for the portion of vessel sound contributed by SOI operations by relating the sound measurements to periods when SOI vessels were near a particular recorder (Chapter 5). However, there was clear evidence of other shipping present including larger diesel–powered vessels that would likely have included barge traffic, other larger supply vessels, and possibly seismic vessels that were not part of SOI activities. Other large vessels in the area included a cruise ship and at least two Coast Guard vessels. The recorders closest to shore generally detected more vessel traffic than the recorders further to sea. It appeared that some of this activity was related to small fishing, hunting, and pleasure vessels. Vessels were the dominant noise source when present. For some vessels the signals were over 40 dB above the mean ambient sound levels.

Additional vessels operating independent of the seismic program included barges, research vessels, and various small boats. Vessel traffic not associated with the seismic programs for which information was available primarily involved barges as described in Chapter 2. The primary mission of fuel barges was to supply communities, and fuel purchases by vessels associated with the seismic operation were incidental. In addition, at least two barges transited the Chukchi Sea enroute to the Beaufort Sea and then passed through the Chukchi Sea again on the return voyage. Several other research vessels also operated in or transited through the Chukchi Sea during 2007.

Beaufort Sea

Industry activities in the Beaufort Sea in the 2007 open water–period involved seismic and shallow hazards surveys conducted by SOI, other activities associated with oil and gas production, and various types of vessel traffic. In addition, fall whaling activities occurred at Kaktovik, Cross Island (Nuiqsut), and Barrow.

***Seismic Activities* —** SOI's source vessel *Gilivar* entered the Beaufort Sea on 12 Sep after conducting seismic exploration activities in the Chukchi Sea. Measurements of the underwater sound produced by the airgun array were conducted by JASCO in Camden Bay on 17–18 Sep and the *Gilavar* collected seismic data from 18 Sep through 3 Oct. The *Gilavar* left the Beaufort Sea on 8 Oct to conduct further seismic survey activities in the Chukchi Sea.

SOI also conducted shallow hazards and site clearance surveys in the Beaufort Sea from the *Henry C.* in 2007. The *Henry C.* entered the Beaufort Sea from Canada on 17 Aug and sailed to eastern Harrison Bay. JASCO measured underwater sound produced from the *Henry C's.* small, two–airgun array and the single mitigation gun on 30 Aug in eastern Harrison Bay and on 14 Sep in Camden Bay before the initiation of seismic activities by the *Gilavar*. From 30 Aug to 3 Oct the *Henry C.* conducted shallow hazards surveys in specific nearshore areas between Thetis Island and Kaktovik. The airgun array on the *Henry C.* was operated during the sound source measurements on 30 Aug and 14 Sep, and for a 12–hr period on 17–18 Sep during survey activity. The airgun array on the *Henry C.* and the *Gilavar* did not operate simultaneously in the Beaufort Sea in 2007. For the remaining portion of the 2007 open–water season in the Beaufort Sea the *Gilivar* airgun array operated on 14 days. All of SOI's seismic activities from the *Gilavar* occurred in a relatively small area offshore of Flaxman Island in western Camden Bay.

In addition to the *Gilavar* and the *Henry C.*, six other vessels contracted by SOI were active at some time in the Beaufort Sea during the 2007 open–water period. Two of these vessels, the *Tor Viking* and *Kapitan Dryanitsyn*, transited the Beaufort Sea but were not involved in any support activities. The *Gulf Provider* was the primary chase/monitoring vessel associated with the *Gilavar* and accompanied the *Gilavar* throughout most of her activities in the Beaufort Sea. The *Norseman II* was involved in the deployment and retrieval of acoustic equipment and also functioned as a chase/monitoring vessel for the *Gilavar*. Bathymetric survey work was conducted from the *American Islander*, and the *Jim Kilabuk* operated briefly in a chase/monitoring capacity for the *Gilavar*.

Underwater sound levels produced by most of these vessels were measured in the Beaufort Sea in 2007. Distances to which underwater received sound levels diminished to 120 dB re 1 μPa rms are reported in SOI's 90–day report (Funk et al. 2008) and ranged from ~400 to 1500 m (437 to 1640 ft) for the smaller vessels, and to ~6300 m (6890 yd) for the *Gilavar*. As discussed above for the Chukchi Sea, sound from these vessels contributed to the overall underwater sound environment. In addition to the vessels contracted by SOI, numerous other vessels operated in support of other industry activities, or in support of village communities. These included various types of tug and barges, research vessels, and smaller boats. Information on many of these activities and vessels is presented in Chapters 2 and 9.

The *Gilavar* conducted seismic survey activities on 14 days from 18 Sep through 3 Oct in a specific block located offshore of Flaxman Island. Hydrophones deployed on either side of the surveyed area recorded sound exposure levels (SELs) as high as ~153 dB re 1 μPa^2–s when the seismic ship was within 25 km or less of the recorders (Chapter 8). [Note that SEL values are not directly comparable with rms levels quoted previously.] Sounds may sometimes have been stronger than this as the recorders overloaded (saturated) when the instantaneous sound pressure exceeded 153 dB re 1 μPa. Analysis of the recorded sounds showed that seismic survey activities caused increased received levels of sound over the entire 10–450 Hz frequency range. Depending on frequency, median levels of sound increased by up to ~40 dB during seismic operations.

The received levels of airgun pulses in particular areas east and west of the area of seismic operations varied over time, but average values depended on distance. Recorders at Site 2 were located ~113 km (70 mi) west of the center of the area of active seismic operations, which was located between Sites 3 and 4. Received SELs (energy levels) at recorder 2A (the southernmost recorder in the array) ranged from 78.1 to 125.9 dB re 1 μPa^2–s with a median value of 105.8 dB, considering one pulse at a time. Received levels at the various recorders in the array varied somewhat. At Site 3 located ~27 km (17 mi) west of the center of the area of active seismic operations, received levels at recorder 3A ranged from 63.5 to 148.2 dB re 1 μPa^2–s with a median value of 129.5 dB. At Site 4 A located ~18 km (11 mi) east of the center of the active seismic survey area, received levels for single pulses ranged from 76 to 151.2 dB with a median of 115.4 dB re 1 μPa^2–s. At site 5, which was ~109 km (68 mi) east of the area of active seismic operations, received levels ranged from 82.2 to 126.3 dB with a median value of 110.3 dB re 1 μPa^2–s. Other seismic pulses from an unknown source were also recorded prior the start of the *Gilavar's* activities. The seismic pulses from the *Gilavar's* array and those from the unknown source could have been detectable at some of the same locations where underwater sounds produced by activities at BP's Northstar Island and at Pioneer's ODS were detectable.

In addition to the seismic survey activities from the *Gilavar*, the *Henry C.* conducted various types of site clearance surveys from 30 Aug to 3 Oct on an intermittent basis as allowed by ice and weather conditions. These operations, which involved higher–frequency, short–range acoustic sources, were located in specific nearshore areas ranging from east of Kaktovik west to Thetis Island near the Colville River delta. Site clearance survey activities occurred on ~23 days during this period. Other than measurement of sounds from the small airgun array on the *Henry C.* on 30 Aug, work in the Thetis Island area involved only higher–frequency, low energy sound sources whose emitted sounds diminished to background levels within a few km from the source (see Chapter 3 in Funk et al. 2008).

Oil and Gas Construction and Production Activities — As described in Chapter 2, a number of independent oil exploration, construction, and production operations occurred in the Beaufort Sea during the open–water period of 2007. These operations did not interact directly, but their operations overlapped temporally. In general, all of these projects potentially increased in–water sound through increased vessel traffic in the areas of operation.

Underwater sound from the *Henry C.*'s activities could have been detectable in some areas where underwater sound produced at Pioneer's ODS development was detectable. However, underwater sound resulting from on–island activities and vessel traffic at ODS were not detected at underwater acoustic recorders located 6.4 km (4 mi) north of ODS during ~two days of recording in 2007 (Laurinolli et al. 2008), and potential overlap in areas (and times) ensonified by ODS and *Henry C.* activities was likely minimal.

Similarly, some of the SOI site clearance activity and vessel operations occurred near BP's oil production operations at Northstar Island. Numerous types of activities are required to support oil production at Northstar. These activities are summarized in Chapters 2 and 9. While SOI activities around Northstar inevitably contributed to in–water sounds in the area, acoustic measurements made near Northstar indicated that levels of low–frequency sound near Northstar in 2007 were similar to those in other years during which measurements were made (Blackwell et al. 2008; summarized in Chapter 9). Underwater ambient sound levels were unusually high in 2007 due to higher average wind speed than in most other years which would have helped to mask other underwater sounds. Furthermore, most underwater sounds from on–island activities at Northstar are only detectable within 2–4 km of the island (Blackwell and Greene 2006) and it is unlikely that there was any significant interaction of sound produced by on–island Northstar activities and the *Henry C*. However, underwater sound from Northstar–related vessel traffic is sometimes detectable to ~30 km distance from the vessel in question (Blackwell and Greene 2005). Such vessel sound could have interacted with underwater sound related to the *Henry C.*'s activities.

***Non–SOI Vessel Traffic* —** Various types of barge traffic in support of industry activities occurred in the Beaufort Sea between Barrow and Kaktovik during the 2007 open–water period. The types of vessel traffic, general location of vessel routes, number of round trips, and timing of barge traffic are discussed in Chapter 2. Barge activities in the Beaufort Sea were conducted primarily in support of land–based exploratory drilling by FEX L.P. near Cape Simpson, construction–related activities at ODS offshore of the Colville River delta by Pioneer Natural Resources, Inc., and oil production activities at Northstar Island by BP Exploration. Various other types of barge and vessel activities were conducted between Barrow and Kaktovik in support of villages and the U.S. Air Force installation at Bullen Point.

Barge routes in the Beaufort Sea were generally near the coast and barges often transited inside the barrier islands. The primary barge routes for industry activities in 2007 were between West Dock and Northstar, Oliktok Point and ODS, and West Dock and Cape Simpson (Figs. 10.5 and 10.6). Other barge traffic that carried general cargo or fuel included several round trips between Barrow and Kaktovik. Also, several vessels transited the entire Alaskan Beaufort Sea during the 2007 open–water period.

In 2007 monthly barge traffic from Oliktok Point to Pioneer's ODS was highest in Aug and significantly lower in Jul and Sep (Table 10.1). No barge activity in support of Pioneer's activities at ODS occurred after 27 Sep. More crew vessel activity associated with ODS occurred in Aug and Sep than Jul and Oct. The underwater sound produced from two vessels associated with Pioneer's ODS activities were measured during ~two days of recording in 2007 (Laurinolli et al. 2008). Sound from the self–propelled barge *Garrett* was measured in both 2006 (Zykov et al. 2007) and 2007. In 2006 the source level measurements were 170.1 and 173.8 dB re 1 μPa at 1 m partially loaded; in 2007 the limited load measurement was 172.5 to 175.1 dB re 1 μPa at 1 m. Although source measurements were similar between years, rms received levels at 500 m (1640 ft) were greater in 2006 by about 6 dB (128 vs. 122 dB re 1 μPa rms in 2006 and 2007, respectively), which was attributed to differences in water depth at measurement locations. Sound source levels for Pioneer's crew vessel in 2007 were 169.7 to 173.5 dB re 1 μPa at 1 m. Underwater noise from Pioneer's barges and crew vessels, and from activities on ODS, were not detected on bottom–founded recorders located 6.4 and 14.5 km (4 and 9 mi) north of ODS. However it was suggested that underwater vessel sounds might have been detectable at the recorder 6.4 km north of ODS had weather conditions been calmer, i.e., with reduced ambient noise levels.

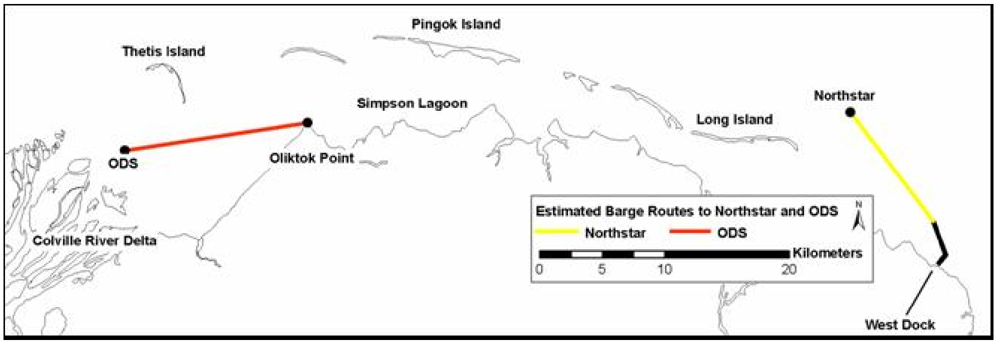

FIGURE 10.5. General location of barge routes from West Dock to Northstar Island and Oliktok Point to ODS 2007.

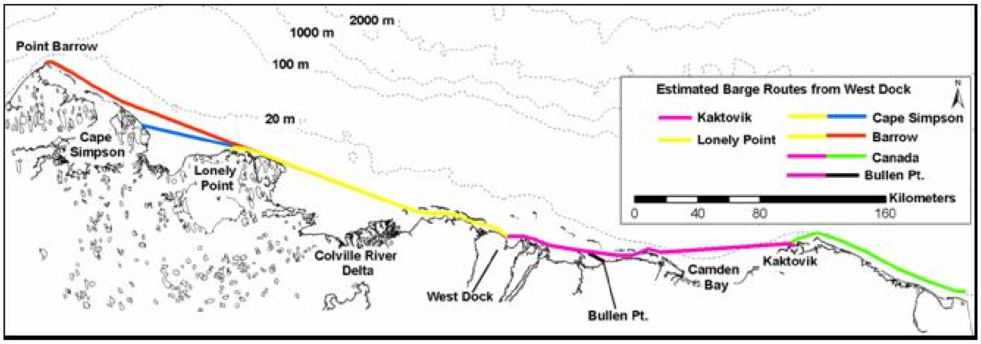

FIGURE 10.6. General location of barge traffic routes in the Alaskan Beaufort Sea between Barrow and the Canadian border, 2007.

Most of BP's barge traffic between West Dock and Northstar Island in 2007 occurred during Aug. Hovercraft use was greater in Jul and Aug, and crew vessels were most active in Aug and Sep. BP has conducted an underwater acoustic monitoring program at Northstar since 2001 (Blackwell et al. 2008). Blackwell and Greene (2006) reported that vessels were the main contributors to underwater sound related to Northstar activities and that vessels were sometimes detectable to ~30 km. In the absence of vessel sounds broadband levels from island activities usually reached ambient within 2–4 km (1.4–2.5 mi). Underwater sound levels produced by BP's Griffon 2000TD hovercraft were considerably lower than those from barges and other conventional vessels of similar size (Blackwell and Greene 2005). McDonald et al. (2007) and Richardson et al. (2007) reported a possible offshore displacement of the southern edge of the bowhead whale migration corridor by as much as 2.24 km (1.39 mi), depending on the year, during periods of higher underwater sound from Northstar.

FEX L.P. conducted 10 barge round trips between West Dock and Cape Simpson in 2007, most of which occurred in Aug (Table 10.1). Sound source levels (rms) for these barges were measured in 2006 and ranged from 162.6 to 182.9 dB re 1 µPa at 1 m (Zykov et al. 2007).

The long distance barge activities between Barrow and the Canadian border in support of activities at Cape Simpson, Lonely and Kaktovik would likely have had a greater potential to cause disturbance to marine mammals than the more localized barge traffic near ODS and Northstar Island. The long distance barge traffic occurred over a broad portion of the Beaufort Sea coast and had the potential to affect marine mammals along the entire route, particularly from Camden Bay eastward.

TABLE 10.1. Number of barge, crew vessel, and hovercraft round trips made by Pioneer between Oliktok Point and ODS, BP between West Dock and Northstar Island, and FEX L.P. between West Dock and Cape Simpson during the 2007 open–water season.

	Pioneer		BP			FEX L.P.
Month	Barge	Crew Vessel	Barge	Hovercraft	Crew Vessel	Barge
July	32	112	3	97	22	1
August	61	183	32	100	41	9
September	36	198	4	36	71	0
October	0	22	1	18	3	0

Subsistence Whaling

Fall subsistence whaling activities for bowhead whales in the Beaufort Sea in 2007 were successful. Three bowheads were landed at each of Kaktovik and Cross Island; one additional whale was struck and lost at Cross Island. At Barrow, seven whales were landed and three were struck and lost during the fall hunt.

During fall, bowhead whales were harvested in the Beaufort Sea during a relatively narrow window of time for each village (Table 10.2) and whalers did not appear to have difficulties in reaching their quotas. Deep seismic acquisition from the *Gilavar* occurred from 18 Sep through 3 Oct and did not coincide with any whaling activities. The airgun and related activities that occurred in the Beaufort Sea in late Aug to measure sound propagation from the airguns onboard the *Henry C.* occurred on 30 Aug, which was the day when the first crew of whalers from Nuiqsut traveled to Cross Island (Galginaitis 2008). The measurement of underwater sound from the small airgun array on the *Henry C.* on 30 Aug apparently did not negatively affect the Cross Island hunt since the first whale was landed on 31 Aug. Whalers at Cross Island did not report any specific conflict with other vessel traffic (Galginaitis 2008).

Bowhead whales are typically hunted from Barrow during spring whaling season in May as well as during the fall. Bowhead subsistence hunts occur primarily in the spring at Point Hope and Wainwright. The numbers of whales landed by villagers in the Beaufort Sea (Kaktovik and Nuiqsut) and the Chukchi Sea (Point Hope and Wainwright) since 1993 are presented in Table 10.3. Whales landed at Barrow may have been taken either from the Chukchi or Beaufort sea. Vessel traffic associated with the seismic program, which began in mid–Jul, would not have affected the spring bowhead hunts.

TABLE 10.2. Dates on which first and last whales were harvested during fall subsistence bowhead whale hunts by coastal villages in the Alaskan Chukchi and Beaufort Seas, 2007. Data from 2007 Fall Bowhead Harvest Report (AEWC).

Village	First Whale	Last Whale	Landed Whales
Kaktovik	3 September	12 September	3
Cross Island	31 August	15 September	3
Barrow	7 October	17 October	7

TABLE 10.3. Number of bowhead whale landings by year at Point Hope, Wainwright, Barrow, Cross Island (Nuiqsut) and Kaktovik, 1993–2007. The numbers for Barrow include the total number of whales landed for the year followed by the numbers landed during the fall hunt in parenthesis.

Year	Point Hope	Wainwright	Barrow	Cross Island	Kaktovik
1993	2	5	23 (7)	3	3
1994	5	4	16 (1)	0	3
1995	1	5	19 (11)	4	4
1996	3	3	24 (19)	2	1
1997	4	3	30 (21)	3	4
1998	3	3	25 (16)	4	3
1999	2	5	24 (6)	3	3
2000	3	5	18 (13)	4	3
2001	4	6	27 (7)	3	4
2002	0	1	22 (17)	4	3
2003	4	5	16 (6)	4	3
2004	3	4	21 (14)	3	3
2005	7	4	29 (13)	1	3
2006	0	2	22 (19)	4	3
2007	3	4	20 (7)	3	3

1 Compiled in USDI/BLM (2003) from various sources.

2 Numbers given for Barrow are “total landings/autumn landings”. From Burns et al. (1993), various issues of Report of the International Whaling Commission, Alaska Eskimo Whaling Commission, J.C. George (NSB Dep. Wildl. Manage.), Suydam et al. 2004, 2005b, 2006, 2007, 2008.

3 Cross Isl. (Nuiqsut) and Kaktovik landings are in autumn. Data compiled in Koski et al. (2005) from various sources.

POTENTIAL EFFECTS OF INDUSTRY ACTIVITIES ON MARINE MAMMALS IN THE CHUKCHI AND BEAUFORT SEAS

Chukchi Sea

Bowhead Whales—Small numbers of bowhead whales may remain in the northern Chukchi Sea through the summer (Moore 1992; Rugh et al. 2003), and these whales may have been exposed to seismic sounds in the Chukchi Sea during late Aug and early Sep. At least some bowheads were probably exposed to seismic sounds during Aug. Recorders deployed in the Chukchi Sea detected bowhead whales at that time. However, no bowheads were seen by aerial surveyors in Aug or Sep in coastal areas of the Chukchi Sea. In general, most bowhead whales would have already migrated through the Chukchi Sea to their summering grounds in the Canadian Beaufort Sea well before the time SOI began seismic operations in the Chukchi Sea in late Aug.

Some of the bowhead whales returning to the Chukchi Sea during their fall migration to wintering grounds in the Bering Sea may have encountered SOI’s seismic operations from 15 Oct through 5 Nov 2007. The somewhat later fall migration in 2007 may have increased the numbers of whales potentially exposed to seismic surveys when compared to 2006. However, in 2006, seismic surveys were much wider ranging and perhaps more likely to encounter migrating bowhead whales, whereas in 2007 surveys were concentrated in a small portion of the Chukchi Sea lease area that was probably easier for whales to avoid. In most areas, (i.e., for all acoustic recorders except one station near the area being surveyed), SPLs were generally 115 dB re 1 µPa or lower (Chapter 5). This sound level was below any level that has been reported to cause reaction in bowhead whales.

Most bowhead whales that encountered airgun sounds from operations in the Chukchi Sea would have been migrating. The response of bowhead whales to seismic surveys can be quite variable depending on the activity of the whales (e.g., migrating vs. feeding vs. socializing). Bowhead whales on their summer feeding grounds in the Canadian Beaufort Sea showed no conspicuous reactions to pulses from seismic vessels at distances of 6–99 km and received sound levels of 107–158 dB on an approximate rms basis (Richardson et al. 1986). Subtle but statistically significant changes in surfacing–respiration–dive cycles were evident upon analysis, but were not noticeable to observers at the time the data were collected. Bowheads usually showed strong avoidance responses when seismic vessels approached within a few kilometers (~3–7 km or 2 to 4 mi) and when received levels of airgun sounds were 152–178 dB on an approximate rms basis (Richardson et al. 1986, 1995). Generally similar results were obtained during a separate study in the eastern Alaskan Beaufort Sea during early autumn (Ljungblad et al. 1988). This work and more recent studies by Miller et al. (2005) found that feeding bowhead whales tended to tolerate higher sound levels than did fall migrating bowhead whales (*cf.* Miller et al. 1999; Richardson et al. 1999). Similar results were reported during seismic surveys in Canadian waters in 2006 (Harris et al. 2007) and in the Alaskan Beaufort Sea during the 2007 seismic activities where whales were also recorded as feeding during aerial surveys (Chapter 7). Additionally, Citta et al. (2007) reported that, in Canadian waters, tagged whales approached within 19 km of an active seismic ship during 2007. Whales were feeding in the area and the seismic ship was shut down in response to other bowhead whales that had entered the "safety zone."

Fall migrating bowhead whales in the Alaskan Beaufort Sea were more responsive to noise pulses from a distant seismic vessel than were summering feeding bowheads. In 1996–98, a partially–controlled study of the effect of Ocean Bottom Cable (OBC) seismic surveys on westward–migrating bowheads was conducted in late summer and autumn in the Alaskan Beaufort Sea (Miller et al. 1999; Richardson et al. 1999). Aerial survey observations showed that some westward–migrating whales avoided an active seismic survey vessel by 20–30 km, and that few bowheads approached within 20 km when the airguns were operating. Received sound levels at those distances were 116–135 dB re 1 µPa (rms). The specific distance at which deflection began could not be determined from the available data, but some whales approaching from the east apparently began to deflect from their migration path at ~35 km from the airguns. In contrast, at times when the airguns were not active, many bowheads moved into the area close to the inactive seismic vessel. Avoidance of the area within ~20 km of the seismic operations did not persist beyond 12–24 h after seismic shooting stopped.

Based on the 1996–1998 (mainly 1998) study of migrating bowhead whales, relatively low levels of airgun sounds (e.g., ≥120 dB re 1 µPa rms) are considered by NMFS (2007) to have the potential to cause disturbance to bowhead whales. There has been concern that bowhead whales subjected to sound pressures ≥120 dB rms may be deflected from the migration routes and therefore less accessible to subsistence hunters. For this reason the IHAs issued for arctic seismic programs in the Chukchi and Beaufort seas in 2006 and 2007 required monitoring of the 120 dB zone (after 25 Sep in the Chukchi Sea).

Few data have been obtained subsequent to the 1996–1998 study to replicate (or otherwise) the observation that migrating bowhead whales avoid areas with relatively low received levels (≥120 dB re 1 µPa rms) of airgun sounds. During a recent cooperative effort by the Alaska Department of Fish and

Game, the Alaska Eskimo Whaling Commission, the North Slope Borough, and the Minerals Management Service, a bowhead whale was tracked from the Barrow area in the spring to the Canadian Beaufort Sea, and then westward through the Beaufort Sea to Barrow (Fig.10.7; Quakenbush 2007). The tracked whale eventually continued west past Barrow in mid–Oct and through the northern Chukchi Sea to the Chukotka coast south of Wrangel Island. As the whale passed Barrow moving westward it approached the eastward moving GXT seismic vessel *Discoverer* on 15 and 16 Oct 2006, and was within the 120 dB radius around the operating airgun array (Fig. 10.7). Sound levels up to 120 dB rms were expected to occur as much as ~58 km fore and aft and ~167 km to the side of the operating airgun array—see GXT 90–day report (Ireland et al. 2007). Within the limits of uncertainty regarding the whale's specific trackline and closest point of approach to the operating seismic vessel, the seismic survey activity from the *Discoverer* did not appear to cause a deflection in the bowhead's migration route.

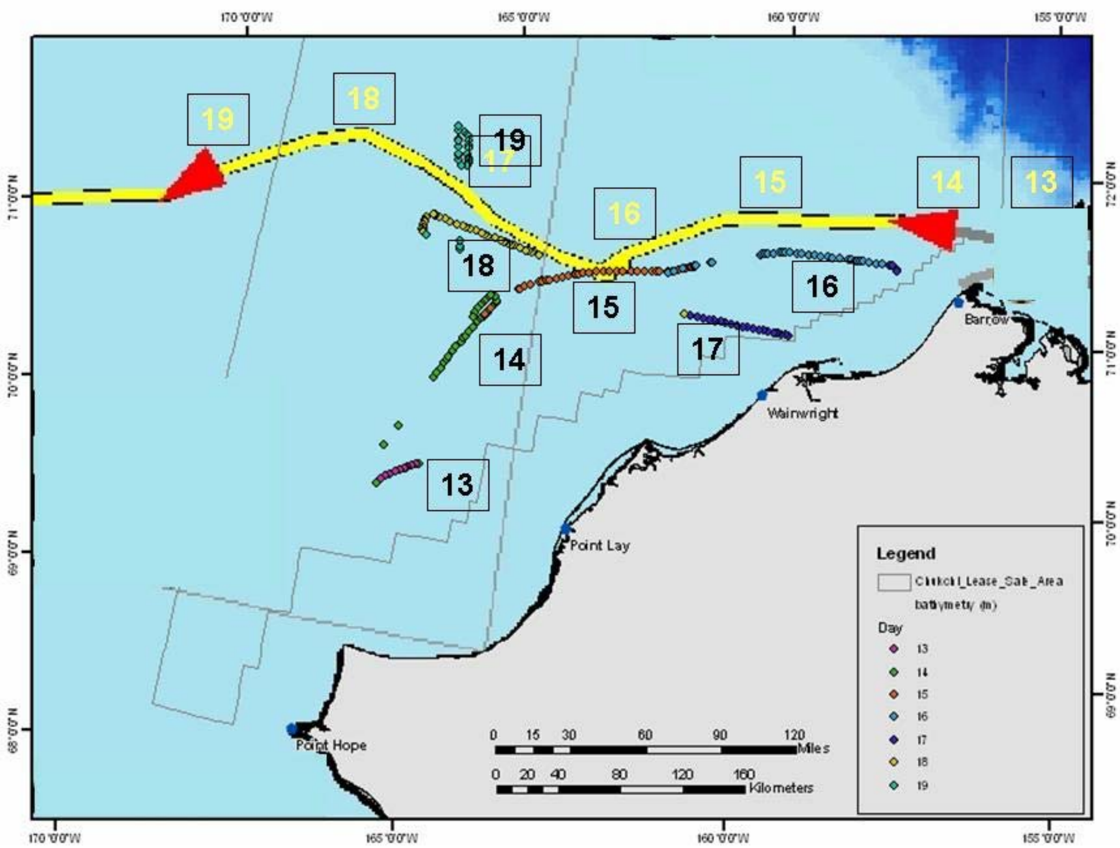

FIGURE 10.7. Tracklines of satellite–tagged bowhead whale (yellow track) and GXT seismic vessel *Discoverer* (dotted track) from 13 to 18 Oct 2006 showing closest point of approach on 15–16 Oct. Data are from Quakenbush (2007) for the bowhead trackline and from GXT for *Discoverer* trackline. Numbered boxes indicate the dates for whale and vessel locations, respectively.

Gray Whales—Gray whales were sighted regularly along the Chukchi Sea coast during aerial surveys in 2006 and 2007. Relatively few gray whales were sighted from vessels except when the vessels were close to shore. The locations of the whales sighted, along with the acoustic measurements from bottom recorders, indicated that gray whales would have been exposed to seismic sounds while feeding or traveling along the coast between Pt. Hope and Barrow from 28 Aug through 10 Sep. In general, the recorders deployed along the coast of the Chukchi Sea showed SPLs that were rarely greater than 115 dB re 1 μPa rms (Chapter 5), making it unlikely that gray whales feeding or traveling along the coast were adversely affected by the sounds from the seismic program that was occurring in offshore waters.

Malme et al. (1986, 1988) studied the responses of feeding eastern gray whales to pulses from a single 100 in^3 airgun off St. Lawrence Island in the northern Bering Sea. They estimated, based on small sample sizes, that 50% of feeding gray whales ceased feeding at an average received SPL of 173 dB re 1 μPa on an (approximate) rms basis, and that 10% of feeding whales interrupted feeding at received levels of 163 dB. Malme at al. (1986) estimated that an average pressure level of 173 dB occurred at a range of 2.6–2.8 km from an airgun array with a source level of 250 dB (0–pk) in the northern Bering Sea. Similarly, studies of western gray whales on their summer feeding grounds off Sakhalin Island demonstrated considerable tolerance of an operating seismic vessel offshore of the feeding area (Johnson et al. 2007). However, there were some subtle behavioral responses (Gailey et al. 2007) and some movement of whales within the feeding area in apparent response to strong airgun sounds (Yazvenko et al. 2007).

These findings from the summer feeding grounds were generally consistent with the results of experiments conducted on larger numbers of gray whales that were migrating along the California coast. Malme and Miles (1985) concluded that, during migration, avoidance occurred for received levels of about 160 dB re 1 μPa and higher, on an approximate rms basis. For a 4000–in^3 airgun array operating off central California, the 50% probability of avoidance was estimated to occur at a CPA distance of 2.5 km where the received level would be ~170 dB re 1 μPa (rms). During the study of migrating gray whales, some behavioral changes were noted at received sound levels of 140 to 160 dB (rms), and it was believed that initial deflection probably began at considerably lower received levels, when the sounds were barely above the background noise level.

Given the relatively high tolerance of gray whales to airgun sounds on summer feeding grounds in the Bering Sea (Malme et al. 1986, 1988) and off Sakhalin island (Yazvenko et al. 2007), it is unlikely that gray whales in the project area would have been disturbed sufficiently by the low levels of sound recorded in coastal areas of the Chukchi Sea in 2006 or in 2007 to have moved away from a feeding area. Reactions to the highest levels of received seismic sounds along the coast would likely have been no more than short–term behavioral responses in 2006 when two seismic programs were operating. The highest received levels in 2007, when only one program was operating, were unlikely to have caused any overt response.

Gray whale use of waters farther from shore in the fall may have been affected by seismic surveys. If shoals within the Lease Sale Area (where gray whales have been observed during aerial surveys) are important feeding habitat, animals using the area may have been affected in 2006. Whales may have been temporarily displaced from those areas and may have been forced to use less optimal feeding habitat. In 2007, it was unlikely that airgun sounds would have displaced gray whales from these areas since recorded sound levels rarely exceeded 115 dB re 1 μPa (rms) except on the recorder positioned close to the area of seismic activity, where received levels were as high as 144 dB. The Sakhalin Island study indicated that feeding gray whales that show local displacement generally remain within the overall feeding area. As the location of the seismic survey activities moved, sound levels in the area would return to background levels and whales could reoccupy preferred feeding areas. While it is possible that a few gray whales were present far enough offshore to have been exposed to enough sound from the airguns to have caused disturbance, it is unlikely that the number of whales affected was high enough to have impacts on more than an individual level.

Beluga Whales Based on aerial surveys along the Chukchi Sea coast (Chapter 4) and on the 2007 acoustic studies (Chapter 5), small numbers of beluga whales from the eastern Chukchi Sea stock were likely still in the Chukchi Sea when seismic survey activities began in late Aug of 2007. Aerial surveys indicated that most beluga whales had left the Chukchi Sea by mid–Sep. Sightings of beluga whales increased in Oct and these whales may have been exposed to seismic activities that were conducted between 20 Oct and 5 Nov.

Beluga whales returning through the Chukchi Sea during the fall migration may have encountered seismic operations. Whales encountering the operating seismic vessel may have altered their course to maintain some nominal distance from the sound source. Effects of seismic exploration and other industry activities on most toothed whales are generally thought to be less than on baleen whales. Beluga whale hearing sensitivity peaks between 10 and 100 kHz and most of the sounds produced by vessels and seismic activities are at much lower frequencies that are less prominent to belugas. Nonetheless, airgun pulses are strong enough, and extend to sufficiently high frequencies, to be audible to belugas 10s of kilometers away (Richardson and Würsig 1997). Although belugas are not likely to react to barely–detectable airgun pulses at those long distances there is evidence that in summer, belugas in the Beaufort Sea tend to avoid operating seismic vessels to distances of 10 km or more (Miller et al. 2005, Harris et al. 2007). In general, beluga whales moving along the Chukchi coast probably did not receive airgun pulses strong enough to elicit overt disturbance, but belugas farther offshore probably would avoid the area around an active seismic vessel.

Seals, Walruses, and Polar bears — In addition to the whales that would, at times, have been exposed to seismic and vessel activities in the Chukchi Sea during summer and fall 2007, ringed, spotted, and bearded seals, and Pacific walruses were also present along the coast and offshore. Previous monitoring work in the Alaskan and Canadian Beaufort seas indicates that seals show no more than localized avoidance of active seismic operations (Miller et al. 1999, 2005; Harris et al. 2001; Moulton and Lawson 2002).

During the open–water period, the highest densities of ***ringed seals*** were most often found within the margin of the pack ice edge. Seismic source vessels towing long streamers cannot operate close to ice because of the risks to equipment towed behind the vessels. However, lower densities of ringed seals also occur in open–water areas where seismic operations occurred. Some ringed seals present in areas of the Chukchi Sea where seismic surveys were ongoing may have been displaced from the area immediately around an operating airgun array. Evidence from previous studies in the Beaufort Sea indicated that ringed seals were not likely to move away from sounds produced by seismic surveys at distances >100–200 m.

Ringed seals (and other seals) that did not move from areas receiving strong seismic sounds may have been exposed to varying levels of impulsive sounds periodically for an extended period of time as the seismic vessel moved back and forth through the seismic survey area. No specific data are available describing the potential for long durations of exposure to impulsive sounds to cause impairment (temporary or permanent) in pinniped hearing. However, there is increasing evidence that seal hearing may be more susceptible to impairment by strong sounds as compared with the hearing of belugas and dolphins (Kastak et al. 2005).

Spotted seal foraging habits are not well understood. Lowry et al. (1998) placed satellite tags on spotted seals at haulouts along the Chukchi Sea coast and reported that spotted seals spent about 16% of their time at haulouts. Seals likely spent a significant portion of the remaining 84% of the time feeding. Chukchi Sea spotted seals traveled as far as 1000 km during foraging trips and they traveled to the Russian coast using haulout sites there during feeding expeditions (Lowry et al. 1998). In 2006, exposure to industry activities may have occurred in offshore areas of the Chukchi Sea. Limited information from prior monitoring studies in the Beaufort Sea indicates that spotted seals occasionally occur close enough to operating seismic vessels to be visible to observers on the source vessel (e.g., Moulton and Lawson 2002). There is no specific information to suggest that spotted seals show greater avoidance of seismic vessels than do ringed seals. Other than the nearshore aerial surveys, no industry activity occurred in coastal areas where disturbance to haulouts would have been possible (during aerial surveys, the aircraft remained at an altitude of 1000 to 1500 ft to minimize disturbance at haulouts). Underwater sound levels reaching haulout areas were probably near ambient according to measurements made in nearshore waters along the Chukchi Sea coast (Chapter 5). Therefore, it is very unlikely that large areas, either offshore or nearshore, were made unavailable to these seals by seismic surveys occurring in the Chukchi Sea. However, seals traveling longer distances to forage may have encountered these seismic activities.

Bearded seals in the Chukchi Sea are more likely to be found near the margin of the pack ice than in the open–water areas where most seismic work occurred. Individuals present near active seismic surveys likely moved away to some limited extent (Harris et al. 2001). Continual or repeated industry activities in a localized area may have displaced some animals from the area, but there was no specific evidence of this.

Walrus abundance and distribution in the study area in 2007 was unusual relative to previous years. Walruses typically use the floating pack ice as a platform from which to forage as long as it remains over relatively shallow waters (<80 m deep), which was the case during much of 2006 but not in 2007 when ice retreated quickly from the Chukchi Sea. Because of their close association with ice (which seismic vessels avoid), few walruses were likely to be affected by industry activities in the Chukchi Sea. As discussed previously, in 2007 walruses were seen in large numbers offshore in open water before the seismic program began operating. Acoustic and aerial survey data indicated that these large groups of walrus moved to haulouts along the Chukchi Sea coast in late Aug and early Sep. Walruses in these haulouts and using the nearshore waters to about 92 km (58 mi) would have rarely been exposed to sound levels greater than 115 dB. Walruses foraging farther from shore may have encountered higher levels of sound from the seismic airguns during the period 28 Aug through 10 Sep when SOI was operating in the Chukchi Sea, and it is possible that these sounds displaced them from potential food resources (most shutdowns of the seismic airguns for marine mammals were in response to walruses). The availability of food resources to walrus along the Chukchi Sea coast and what effect, if any, the use of terrestrial haulouts along the coast will have on them is not well understood. Walruses were no longer observed at the terrestrial haulout sites after 8 Oct and they presumably headed south to their wintering areas in the Bering Sea. SOI conducted additional seismic acquisition from 20 Oct through 5 Nov, but this was after most walrus had left the study area.

Polar bears were not observed in the Chukchi Sea at any time during the 2007 season from any of our survey platforms and only a few were seen in 2006. When polar bears are in the water, they are near the surface where sounds from seismic sources tend to be lower due to pressure release effects (Greene and Richardson 1988). Their habit of swimming at the surface also makes polar bears relatively easy to observe from a vessel. The direct effects of industry activities in the marine environment on polar bears were, at most, very limited in 2006 and 2007.

Beaufort Sea

Bowhead Whales — Most bowhead whales are thought to feed in the Canadian Beaufort Sea during the summer months and migrate through the Alaskan Beaufort Sea during fall (Mate et al 2000; Schick and Urban 2000). Fall migration through the Alaskan Beaufort Sea begins in late Aug or early Sep and continues into Nov (Burns et al. 1993 and references therein). The MMS has conducted annual aerial surveys of the Beaufort Sea to monitor the bowhead whale fall migration since 1979 (e.g., Monnett and Treacy 2005). Some early migrating bowheads may occur in the Beaufort Sea in early Aug; alternatively, some bowhead whales may spend the summer in the Beaufort Sea. Sightings of bowhead whales in the Beaufort Sea in Aug are not uncommon. In 2007 Green et al. (2007) reported sightings of 38 bowhead whales in mid–Aug at Smith Bay east of Barrow, and Goetz et al. 2008 reported 49 bowheads northeast of Barrow on 23–24 Aug 2007.

The peak of the bowhead migration in the Beaufort Sea generally occurs later in Sep. Blackwell et al. (2008) reported three peaks in bowhead calls recorded near Northstar Island on 29–30 Aug, 7 Sep, and 15–21 Sep in 2007. During aerial surveys in 2006 and 2007 in the vicinity of the seismic surveys (Chapter 7), bowhead whales were observed during the first surveys each year on 26 and 22 Aug, respectively, but peak sighting rates occurred during mid– to late Sep. Bowheads were also observed by MMOs on the *Gilavar* and on support vessels during the seismic surveys which began in mid–Sep 2007 (Chapter 6).

The *Gilavar* entered the Beaufort Sea on 12 Sep and conducted seismic activities on 14 days from 18 Sep through 3 Oct. Seismic activities were conducted in a relatively small area north of Flaxman Island between Deadhorse and Kaktovik in SOI lease holdings (see Fig. 2.2 in Chapter 2). After completing the seismic activities the *Gilavar* left the Beaufort Sea on 8 Oct to continue exploration activities in the Chukchi Sea. Based on density estimates calculated from observations during aerial surveys, 40 and 192 bowheads were estimated to have been exposed to sound levels ≥180 and 160 dB rms, respectively, during seismic activities in 2007 (Chapter 7). These are likely overestimates of the numbers of exposures since many bowheads may have avoided the survey area (Richardson et al. 1986, 1995, 1999; Miller et al. 1999). However, some evidence suggests that bowheads may be more tolerant of sound when feeding than during migration (Miller et al. 2005), and feeding was the primary behavior recorded during the 2007 aerial surveys. During the 2007 aerials surveys, bowhead sightings tended to be slightly further from the center of the prospect during seismic and post–seismic periods than during non–seismic periods, although this trend was not significant.

The *Henry C.* entered the Beaufort Sea from Canada on 17 Aug and conducted shallow hazards and site clearance surveys on 23 days from 30 Aug through 3 Oct. The safety radii for cetaceans and pinnipeds during shallow hazards work were small compared to the safety radii for the deep seismic activities of the *Gilavar*, given the relatively small size of airgun system used during the former. Eight bowhead whales were observed by MMOs onboard the *Henry C.* in 2007, one during post–seismic and seven during non–seismic periods (Chapter 6). Based on the densities of marine mammals estimated from aerial observations during non–seismic periods, no bowhead whales were likely exposed to received sound levels ≥180 dB rms from activities associated with the *Henry C.*

Analyses of data collected from DASAR arrays in the vicinity of the 2007 seismic activities provided evidence of bowhead response to underwater seismic sound (Chapter 8). Bowhead call rates were significantly higher at recorders near the seismic survey area before the airguns began firing than during periods of airgun activity. This difference in calling rates between seismic and non-seismic periods was not observed at recorders located further from the seismic survey area where received sound levels from the airguns were reduced. The difference in calling rates at the various recorder sites could not be explained by factors such as weather or potential masking of the calls by the seismic pulses. The reduction in call rates during seismic periods could have been due to displacement of some whales to areas further away from the seismic survey activities (and the recorders). However, call rates increased near the recorders during breaks in the seismic airgun activity suggesting that at least some bowheads remained in the area but altered their calling patterns in response to the seismic survey activities. Aerial survey data (Chapter 7) also suggested that bowheads did not appear to move significantly further from the location of the seismic survey activities after the onset of airgun activity.

Based on quantile regressions of distance from shore for bowhead call locations, there was a general trend for locations of calls to change during seismic activities compared to the distribution of call locations recorded before onset of seismic operations at some sites (Chapter 8). The two closest sites to the seismic survey activities were sites 3 and 4 located ~29 and 18 km (18 and 11 mi) west and east of the survey area, respectively. At Site 3 the distance of call locations from shore tended to decrease for locations within ~2/3^{rds} of the quantiles closest to shore (i.e., the lower 2/3^{rds} of the distribution) suggesting possible shoreward deflection of bowheads in response to seismic activities. At Site 4 located near the eastern edge of the seismic survey area, the upper 1/3rd of the call distribution was significantly further offshore after onset of seismic activities suggesting possible offshore deflection in response to the seismic activities. In both cases it was also possible that whales further from the seismic activities were calling at a higher rate due to exposure to lower received sound levels with increasing distance from the exploration activities. This would produce the same result in call distribution as whale deflection away from the sound source. At Site 5, located ~105 km (65 mi) east of the seismic survey area, no effect on call distribution in relation to seismic pulses was noted. At Site 2, located ~177 km (110 mi) west of the seismic survey area, there was a slight increase in the offshore distance of the lower 1/3rd of the call distribution which might be explained by the wider continental shelf (and shallower water) at this site compared to sites 3 through 5.

However, the distribution of calls at Site 3 on 5 Oct (2 days after completion of seismic activities) was widely dispersed over a large area further offshore than prior to and during seismic operations. At Site 2 located ~90 km (56 mi) west of the seismic activities, the offshore distribution of bowhead calls detected by the array was wider before seismic activities than at Sites 3 and 4 and there was a trend for calls to occur further offshore as the season progressed. The general trend for whales to be seen farther offshore as the season progressed was expected because the migration is size structured with small bowheads migrating early in the season and large bowheads migrating near the end of the migration (Koski and Miller 2002). Small or subadult bowheads feed and travel through shallow nearshore waters and large or adult bowheads feed and migrate farther offshore. However, bowhead calls were not as widely dispersed over as large an area after seismic activity at Site 2 compared to Sites 3 and 4. In general, the northward deflection of bowhead calls in apparent response to seismic sound was greater at the sites near the seismic activity (Sites 3 and 4) compared to the site further away (Site 2; see Fig. 8.13 in Chapter 8).

Bowhead whales in the Beaufort Sea could have also been affected by other activities not associated with SOI's seismic exploration. Lower level seismic pulses of unknown origin were detected from the DASAR arrays at Sites 2, 3, 4, and 5 in 2007 (Chapter 8). Sound exposure levels (SELs) of these pulses were generally lower than 120 dB re 1 $\mu Pa^2 \cdot s$

Bowhead whales were also exposed to non–seismic vessel traffic associated with SOI's seismic program (i.e., support vessels used during monitoring activities and deployment and retrieval of acoustic equipment) and various types of barges and other vessel traffic associated with industry or other activities between Barrow and the Canadian border. The extent of this vessel traffic is discussed in the next section on *Potential Cumulative Effects*. Bowhead whale sighting rates have generally been lower during seismic than non–seismic periods during vessel based observations in support of seismic operations suggesting avoidance of seismic operations. Non–seismic vessel traffic has less potential to result in changes in bowhead behavior and distribution than vessels engaged in seismic activities. Green et al. (2007) did not detect bowhead whale (or other cetacean) reactions to barges in Smith Bay in 2007. Green et al. (2007)

also reported that most seals (71%) showed no reaction to the barges, although 6% showed strong reactions.

Offshore activities at BP's Northstar Island and Pioneer's ODS emit sounds into the water that may also have the potential to affect bowhead whale behavior and distribution. Underwater sounds result from on–island activities and vessel traffic used for transportation of personnel and equipment to and from the islands. After multi–year studies at Northstar Island, McDonald et al. (2007) reported subtle offshore displacement of the southern edge of the bowhead migration corridor in response to underwater sound related to Northstar activities. This effect was only apparent after intensive statistical analyses.

Pioneer's ODS is located inshore of the barrier islands in shallow water ~1–2 m (3–6 ft) deep. The bottom gradually slopes to ~13 m (43 ft) of water depth about 14.5 km (9 mi) north of ODS and bowhead whales would not be expected to occur in the immediate vicinity of ODS. However, Laurinolli et al. (2008) recorded bowhead whale vocalizations on bottom–founded recorders located 6.4 km (4 mi) north of ODS. It is not clear how far the whales were from ODS since the equipment used to make the recordings was not capable of determining the locations of the calling whales. During limited aerial surveys at ODS four bowhead whales were observed ~35 km (22 mi) northeast of ODS (Williams et al. 2008). Data from the annual BWASP surveys have documented 86 bowhead sightings within 32 km (20 mi) of ODS since 1979, the closest of which was ~9 km (5.5 mi) from the current location of ODS. Measurements of underwater sound resulting from vessel traffic associated with ODS and on–island activities were not detectable on recording equipment located 6.4 km (4 mi) north of the island. It seems unlikely that underwater sounds associated with ODS would have a significant effect on bowhead whales.

Gray and Beluga Whales — Gray whales occur in nearshore areas, but are not common in the Beaufort Sea. Small numbers of gray whales have been reported along the coast of the Alaskan and Canadian Beaufort Sea in summer (Rugh and Fraker 1981; Miller et al. 1999; Treacy 2002). Two and one gray whale sightings were recorded during vessel–based observation in the Beaufort Sea in 2006 and 2007, respectively, and few gray whales were recorded during aerial surveys. Gray whales occur regularly in the Beaufort Sea but are uncommon. Few if any gray whales were likely to be affected by SOI's seismic activities because they occur in nearshore areas where received seismic sound levels are low.

Beluga whales were not reported during vessel–based operations in 2006 or 2007 in the Beaufort Sea. However beluga whales were frequently observed during aerial surveys in both years. Beluga whale sighting rates and numbers of individuals recorded during aerial surveys were higher in 2006 than 2007 (Chapter 7). Beluga whales were generally recorded further offshore than bowheads. Moore (2000) and Moore et al. (2000) reported that beluga whales in the Beaufort Sea use deeper slope habitats in contrast to shelf habitats used by bowheads. Beluga whales may avoid seismic activities by as much as 20 or 30 km (Miller et al. 2005) but the normal migration corridor of belugas is well north of areas where seismic operations were conducted during both 2006 and 2007. No beluga whales were recorded during aerial surveys during periods with seismic activities in 2007, and no belugas were estimated to have been exposed to received sound levels ≥160 dB rms.

Seals, Walruses, and Polar Bears — Seals were the most abundant marine mammals observed during vessel–based surveys in the Beaufort Sea in 2007 (Chapter 6). Ringed seal is the most abundant seal species in the Beaufort Sea and is a year–round resident. Bearded and spotted seals are also regularly observed in the Beaufort Sea in smaller numbers. Pacific walruses occur in the Beaufort Sea but are uncommon. Five sightings of nine Pacific walruses were recorded in the Beaufort Sea during vessel–based activities in 2007.

As discussed in the previous section on the Chukchi Sea, seals in the Beaufort Sea may also be more tolerant of anthropogenic activities and underwater sound than cetaceans (Harris et al. 2001; Miller et al. 1999, 2005; Harris et al. 2001; Moulton and Lawson 2002; Moulton et al. 2003). However, sighting rates of pinnipeds from both source and support vessels in the Beaufort Sea in 2007 were higher during non–seismic than seismic periods suggesting some localized avoidance of seismic activities. Seals were initially recorded at closer distances to both vessel types during non–seismic than seismic periods, although the differences were not great and sample sizes were insufficient to make firm conclusions.

The estimated numbers of pinnipeds that would have been exposed to received sound levels ≥190 dB re 1ųPa (rms) if they did not move away from the source vessels, were 27 and one based on non–seismic pinniped densities for the *Gilavar* and *Henry C.*, respectively. However, as discussed above, there was evidence of localized movement away from the source vessel, so the actual numbers exposed to this level were probably lower. The numbers of seal exposures for the 160 dB rms disturbance radius were 149 and 63 for the *Gilavar* and *Henry C.*, respectively.

A few polar bears were sighted in the Beaufort Sea during industry activities, either swimming or on ice. All polar bears seen during aerial surveys were either on land or in the water near barrier islands, well south of seismic operations. No seismic survey activity, and little other vessel activity, occurred in ice–covered waters or on land where polar bears are most abundant during the late summer and early autumn. The direct effects of industry activities in the marine environment on polar bears were, at most, very limited in 2007.

POTENTIAL CUMULATIVE IMPACTS

Cumulative effects to a species or a group of species may result from the accumulation of impacts of all previous, current, and future activities that have the potential to affect the species or species group on a population level. MMS (2007) identified past, present, and potential future human activities and possible naturally occurring phenomenon that may incrementally affect and thus have cumulative impacts on bowhead whales and other marine mammal species in the Chukchi and Beaufort seas. Past, present, and potential future actions that have the potential to impact marine mammals in the Chukchi and Beaufort seas include:

- historic commercial whaling;
- past, current, and future subsistence hunting;
- previous, current, and near–term future oil– and gas–related activity;
- previous, current, and near–term future non–oil and gas industrial development;
- past, current, and near–term future research activities;
- recent, current, and future marine vessel traffic and commercial fishing;
- pollution and contaminants; and
- Arctic climate change.

Commercial Whaling

Commercial whaling from 1848 to about 1915 resulted in depletion of the BCB bowhead whale population. Woody and Botkin (1993) estimated that the historical population for the BCB bowhead population was likely between 10,400 and 23,000 animals prior to commercial whaling, and that about 1000 to 3000 whales remained in 1914. Commercial hunting was discontinued around 1915 and the current BCB bowhead population has recovered to above the lower limits of the historical population estimates. The most recent population estimate indicates a 2001 BCB bowhead population of 10,545 whales with a confidence interval ranging from 8200 to 13,500 (Zeh and Punt 2005). From 1978 to 2001 this population grew at ~3.4% per year (95% CI = 1.7 to 5%; George et al. 2004; Zeh and Punt 2005) and if it continued to grow at this rate, the 2007 population was ~12,900 whales.

Subsistence Whaling

The growth of the BCB bowhead whale population has continued in spite of annual Native subsistence hunts from coastal villages in Alaska and Russia. Subsistence hunts have been conducted for several thousand years and far fewer whales were taken annually during subsistence hunts than during commercial hunting activities. There is no evidence that past and current subsistence hunts have affected bowhead whales at the population level, and in fact, data indicate that the population has grown at 3.4% per year. Subsistence hunts for bowhead whales are managed cooperatively by the NMFS, the International Whaling Commission (IWC), and the Alaska Eskimo Whaling Commission (AEWC) under the Whaling Convention Act. Under the preferred alternative of an EIS prepared by NMFS (2008), the AEWC would be granted an annual strike quota of 67 bowhead whales, not to exceed a total of 255 landed whales over the five year period 2008 through 2012, with no more than 15 unused strikes from the previous year added to the annual strike quota. This alternative would continue management of the bowhead subsistence hunt as in the recent past. Because current technology has increased the efficiency of subsistence hunts and fewer whales have been struck and lost during recent years than during the early years of the hunt (Suydam 2004), the BCB bowhead population is expected to increase under the current quota system. Subsistence hunting does not appear to have affected bowhead whales at the population level and NMFS (2008) rated the overall impact of the bowhead subsistence hunt under the preferred alternative as negligible.

Subsistence hunts for beluga whales occur annually at Point Lay on the Chukchi Sea coast and opportunistically at other locations in Alaska. The subsistence harvest of beluga whales from the Eastern Chukchi Sea stock averaged 65 whales annually from 1999–2003 (Angliss and Outlaw 2007). Most of these whales were probably harvested by villagers from Pt. Lay. In 2007 ~70 beluga whales were harvested south of Pt. Hope by villagers at Kivalina in late July. Beluga whales had not been seen in large numbers in this area since the mid–1990s. There was speculation that seismic activities had helped drive the whales close to shore but the harvest occurred well before the beginning of seismic activities in the Chukchi Sea in late Aug. The most recent estimate of the size of the Chukchi Sea beluga population is 3710 whales although some evidence (Suydam et al. 2001) suggests overlap in the range of this population with the larger Beaufort Sea population estimated at nearly 40,000 whales (Angliss and Outlaw 2007). Subsistence harvest of beluga whales in the Chukchi Sea does not appear to affect this species on a population level, although subsistence hunting of other beluga whale stocks may have had population level impacts (Mahoney and Sheldon 2000).

Angliss and Outlaw (2007) reported that the Beaufort Sea harvest of beluga whales by Alaska Natives averaged 53 whales from 1999 through 2003. There is no information available on the locations of the beluga whale subsistence hunts in the Alaskan Beaufort Sea or which villages participate in the hunts. Angliss and Outlaw (2007) also reported that the annual subsistence harvest of belugas in the Canadian Beaufort Sea averaged 99 whales during the five–year period 1999 through 2003. The minimum population estimate for the Beaufort Sea beluga population is 32,453 based on an aerial survey conducted in 1992 with a correction factor of 2 to account for availability bias (Angliss and Outlaw 2007). Because the 1992 survey covered only a small part of the summer range of Beaufort Sea belugas (Richard et al. 1997, 2001), it is very likely that the population is much larger than 32,453.

Native communities also conduct subsistence hunts for other marine mammal species including ringed, bearded, and spotted seals, and Pacific walrus. Seals are much less high–profile species than bowhead whales and subsistence hunts for seals are less regulated. There are no current estimates of the numbers of ice seals (ringed, bearded, and spotted seals) taken annually during subsistence hunts. The Alaska Department of Fish and Game collected subsistence data on annual seal harvests that were based on information collected prior to 2000 (Angliss and Outlaw 2007). The estimates for annual subsistence harvests of ringed, bearded and spotted seals were 9567, 6788, and 5265, respectively. The current population estimates for each of these seal species is in the hundreds of thousands and current level of subsistence harvests are not expected to affect these species at population levels.

The size of the Pacific walrus population is not known with certainty. Pacific walruses have been hunted commercially in the past and it is likely that the population has fluctuated markedly (Angliss and Outlaw 2007). The actual numbers of walruses currently harvested during subsistence hunts are unknown. The USFWS bases their current estimate of the annual Pacific walrus harvest on the average number of walruses harvested during the 5–year period 1996–2000 resulting in an annual estimated harvest of 5789 animals. Although there are no current estimates of the size of the Pacific walrus population, it likely numbers around 200,000 animals and the current level of harvest is not expected to impact Pacific walrus at the population level (Angliss and Outlaw 2007). Recent declines in sea ice concentration in the Arctic have raised concerns for walruses due to their reliance on pack ice to haul out near feeding areas in summer. It is thought that declines in the pack ice might result in poorer nutritional health of walrus and declines in the population. (Cooper et al. 2006).

Subsistence and sport hunting of the southern Beaufort Sea population of polar bears has occurred in Alaska and Canada. The greatest harvest numbers were reported in the mid– to late 1960s when aerial hunting was permitted (Angliss and Outlaw 2007). Aerial hunting was prohibited in 1972 and current harvest levels are much lower. A management agreement between the Canadian Inuit and the Alaskan Inupiat regulating polar bear hunts has been in place since 1988. The harvest in Canada is regulated by a quota system and in Alaska by voluntary actions of local hunters. The combined annual harvest of southern Beaufort Sea polar bears in Alaska and Canada was 51.8 animals for the period 1995–2000 (Angliss and Outlaw 2007).

Oil Industry Activities

Offshore Oil and Gas Exploration — Various types and levels of underwater sound are produced during activities associated with offshore oil and gas exploration and development. Sounds from seismic vessels using airgun arrays produce sound pressure levels which may extend tens or hundreds of kilometers from the source before declining below ambient levels. The extent of above–ambient sound levels depends on numerous variables including output of the airgun arrays, water depth, bathymetry, sediment composition, presence of permafrost and currents. Above–ambient sounds are also produced by engine and propeller activity of seismic and support vessels involved in seismic exploration activities. Some types of vessels, such as icebreakers, which are often used as support vessels during exploration in the Arctic, may produce greater underwater sound levels than others, such as smaller chase/monitoring vessels or other support and research vessels (Greene 1987b; Hall et al. 1994) Increased sound levels during icebreaking activity results from propeller cavitation rather than ice breaking (Richardson et al. 1995). Underwater sound is also produced during exploratory drilling from drill ships or offshore islands (Greene 1987a). Underwater sound from drilling activity occurs at lower levels than that produced from large airgun arrays; however unlike seismic sound which is pulsed, drilling sounds are continuous.

Various other types of underwater sounds may be introduced into the environment during activities associated with oil and gas production. These may include sounds produced by heavy equipment used during construction of ice roads, gravel islands and subsea pipelines, and during production and maintenance activities (Blackwell et al. 2004a; Blackwell and Greene 2006).

Underwater sound has the potential to cause disturbance to marine mammals and there is concern that high levels of sound may cause temporary or permanent hearing impairment to some species or individual marine mammals. However, the levels at which hearing impairment might occur are well above levels that are produced by all but the strongest sound sources (Southall et al. 2008). There is also concern that lower levels of sound may cause changes in the behavior of some species. Masking can occur if ambient sound, including sound produced during industrial activities, interferes with a marine mammal's ability to detect calls from conspecifics or predators, echolocation pulses, or other important natural sounds in the environment (Richardson et al. 1995). Some behavioral changes such as temporary changes in breathing or diving rates, or avoidance behavior, may not result in biologically significant impacts to individual marine mammals or to marine mammal populations. However, disturbance that causes avoidance of preferred feeding or resting areas could affect energy budgets and result in reduced rates of adult or calf survival. Also, of direct relevance to subsistence hunting, changes in distribution might result in fewer animals being available for harvesting during subsistence activities. It is not known if multi–year exposure of marine mammals to seismic sounds from one or more seismic operations may eventually result in impaired hearing abilities though wide variation among species and individuals would be expected.

Seismic programs have operated in the Beaufort and/or Chukchi seas since the late 1960's with more than 16,000 km (10,000 line miles) being shot in some years (Fig. 10.8). This seismic activity was coincident with an increase in the bowhead whale population which continues to grow at a rate of ~3.4% per year based on current estimates (George et al. 2004; Zeh and Punt 2005).

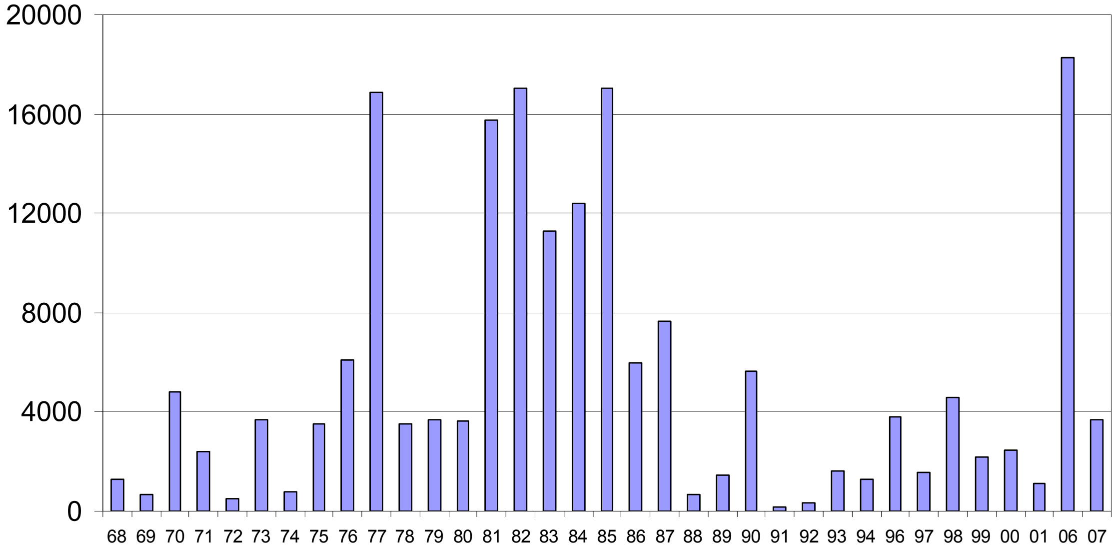

FIGURE 10.8. Kilometers of seismic activity using towed arrays from 1968 through 1994, and 2006 and 2007 in the Chukchi and Beaufort seas. On bottom cables (OBC) were used to conduct seismic activity in 1996–2001 in the Beaufort Sea.

Many cetaceans are known to avoid seismic activities (Richardson 1995; Miller et al. 1999) while there may be less avoidance of such sounds by some pinniped species (Harris et al. 2001; Miller et al. 2005). Individual marine mammals may respond differently to sound stimuli depending on their activities. Richardson et al. (1986) reported that most bowhead whales began to orient away from seismic airguns in the Canadian Beaufort Sea at a distance of 7.5 km, but that some whales continued feeding until the vessel was 3 km away. Richardson et al. (1999) reported that most bowhead whales during their autumn migration avoided areas within ~20 km of operating seismic airguns. Miller et al. (2005) reported numerous sightings of bowhead whales during aerial surveys at distances from 5.3 to 19.9 km from an operating seismic vessel, and substantial numbers of bowheads were recorded at closer distances by observers onboard the vessel. During the same study Miller et al. (2005) reported that beluga whales appeared to avoid the seismic operations by distances up to 20 km. Cetacean avoidance of seismic vessels is related to received sound levels and may also be related to whale activity. Some evidence suggests that migrating bowhead whales are less tolerant of underwater seismic and other sounds than are feeding whales (Richardson et al. 1986; Miller et al. 1999, 2005).

Recent seismic exploration activities were conducted in the Chukchi Sea in 2006 and in the Chukchi and Beaufort seas in 2007. Three seismic vessels operated by SOI (*Gilavar*), CPAI (*Western Patriot*), and GX Technology (*Discoverer*) were active in the Chukchi Sea in 2006. No deep seismic exploration was conducted in the Beaufort Sea in 2006 although a small airgun array was used for about 12 hr during shallow hazards surveys. SOI conducted seismic operations in the Chukchi and Beaufort seas in 2007 as well as shallow hazards surveys in the Beaufort Sea which involved limited use of a small airgun array.

The total number of km of seismic trackline and number of days of seismic shooting in the Chukchi Sea were greater in 2006 than 2007 (Tables 10.4 and 10.5). Total vessel traffic (in km) associated with seismic activities in the Chukchi Sea in 2006 was also much greater than in 2007. This was due to reduced seismic exploration using only one seismic source vessel (and associated support vessels) in the Chukchi Sea in 2007 compared to three seismic source vessels in 2006.

Seismic exploration had been planned for the Beaufort Sea in 2006 but was cancelled due to ice conditions. Consequently, total vessel traffic related to seismic exploration activities in the Beaufort Sea in 2007 was much greater than in 2006 (Table 10.4). Vessel traffic in the Beaufort Sea in 2006 resulted primarily from shallow hazards and site clearance surveys by the *Henry C*. The *Discoverer* and *Kilabuk* each transited the Beaufort Sea enroute to or from Canada.

Vessel traffic during oil and gas exploration in the Beaufort Sea in 2007 resulted from several types of activity. A significant source of vessel traffic included the seismic vessel *Gilavar* and its chase/monitoring vessel, and the shallow hazards vessel *Henry C.* (Table 10.4). SOI also conducted an extensive research program in the Beaufort Sea in 2007 involving vessel–based activities for deployment and retrieval of various types of acoustic monitoring equipment (*Norseman II* and *Nanuq*) and for bathymetric studies (*American Islander*). Three vessels, the *Fennica, Kapitan Dranitsyn,* and *Tor Viking*, transited the Beaufort Sea enroute to Canada.

TABLE 10.4. Numbers of kilometers transited by seismic vessels (bold) and various types of support vessels (non–bold) during seismic exploration activities in the Chukchi and Beaufort seas in 2006 and 2006. Non–bold numbers indicate total trackline for each vessel and year. Bold–faced numbers are estimated number of km of seismic production line.

	Chukchi Sea		Beaufort Sea	
	2006	2007	2006	2007
American Islander	-	2774	-	2352
Discoverer	6071	-	752	-
Seismic	**3128**	-	-	-
Fennica	-	624	-	1068
Gilavar	14503	5053	-	5328
Seismic	**5297**	**2916**	-	**792**
Gulf Provider	18,609	13,366	72	5839
Henry Christoffersen	-	-	8213	4769
Kapitan Dranitsyn	-	1905	-	1425
Kilabuk	15,865	-	874	2381
Kootook	-	-	-	32
Nanuq	-	4320	-	6494
Norseman II	-	11,688	-	8175
Octopus	6157	-	-	-
Patriot	19,168	-	-	-
Seismic	**9855**	-	-	-
Torsvik	25,390	-	49	-
Tor Viking	-	625	-	1073
Total Traffic	**105,763**	**40,355**	**9960**	**38,936**
Total Seismic Traffic	**18,280**	**2916**	**0**	**792**

TABLE 10.5. Number of vessel−days during which at least one airgun was fired during seismic exploration activities in the Chukchi and Beaufort seas during 2006 and 2007. Beaufort Sea numbers include one day each in 2006 and 2007 for survey activities of the *Henry C*.

	Seismic/vessel days		
Year	Chukchi Sea	Beaufort Sea	Period
2006	155	1	27 July–11 November
2007	30	15	28 August–4 November

Ongoing seismic exploration in the Canadian Beaufort Sea during recent years also has the potential to affect bowhead whales and other marine mammals. Most recently, seismic activities were conducted in 2006 and 2007 in the eastern Canadian Beaufort Sea. Bowhead whale was the most frequently sighted marine mammal species during vessel–based observations from the seismic vessel in 2006 (Harris et al. 2007). Bowhead sighting rates were higher during periods when seismic guns were firing that during non–seismic periods, which was the opposite of what would be expected if the whales were avoiding seismic activities. However, the comparison may be biased due to the relatively low amount of survey effort during non–seismic periods. Few beluga whales were observed by vessel–based MMOs, but sighting rates during aerial surveys were greater for belugas than bowheads suggesting possible avoidance of the seismic vessel by belugas as was noted in earlier years by Miller et al. (2005). Whether any biologically significant effects to bowhead or beluga whales resulted from the seismic activities in 2006 is unknown. Continued seismic exploration activities in the Canadian Beaufort Sea will add incrementally to the potential for exploratory activities to affect bowhead and beluga whales by increasing the amount of time that marine mammals that migrate from Canadian waters through Alaskan waters would be exposed to seismic airgun sounds each year. The estimated numbers of exposures of cetaceans and pinnipeds in the Chukchi and Alaskan Beaufort seas to various received sound level ≥160 dB rms in 2006 and 2007 are presented in Chapters 3 and 6.

There has also been concern that underwater seismic energy may have the potential to impact benthic invertebrates and plankton that provide food for marine mammals. Relatively few studies have been conducted on the impacts of seismic activity on marine invertebrates. Christian et al. (2004) reported that snow crabs did not show any chronic or long–term effects after exposure to single airgun and seven–airgun array sources. The crabs were positioned 2–4 m (6.5–13 ft) from the sound sources where relieved levels were 221 to 224 dB re 1 μPa $_{0\text{ to peak}}$ (~218 to 221 dB rms). Payne et al. (2007) reported no effects on mortality or mechanosensory systems of lobsters exposed to low level (~202 dB $_{\text{peak to peak}}$) or high level (~227 dB $_{\text{peak to peak}}$) sound pulses. However sublethal effects were observed with respect to feeding and serum biochemistry weeks to months after exposure. These initial experiments were meant to be exploratory and the authors stressed the need for caution when interpreting the results. Andriguetto–Filho et al. (2005) did not detect significant impacts to several shrimp species after exposure to seismic energy. In a review of available information on the effects of seismic sound on invertebrates, DFO (2004) reported that lethal or sublethal effects from exposure to seismic energy have been reported for some invertebrates exposed close to airguns, but considered exposure to seismic sound unlikely to result in direct invertebrate mortality.

Offshore Oil and Gas Production — Oil and gas are currently being produced from BP's offshore development at Northstar Island, and Pioneer is developing an offshore island (ODS) in eastern Harrison Bay for future oil and gas production. Northstar is located outside of the barrier islands ~10 km (6 mi) offshore of Pt. Storkerson in the Prudhoe Bay area. ODS is located inside the barrier islands near the Colville River delta. No other offshore oil and gas production developments currently exist in the Alaskan Beaufort Sea, and no similar production developments exist in the Chukchi Sea.

Northstar Island and ODS are both man–made, gravel islands. Much of the island construction activities occurred during winter months when heavy equipment was used for island construction and installation of subsea pipelines. The only marine mammal species likely to occur in the general area of the developments during winter were ringed seal and polar bear. Blackwell et al. (2004a) reported that underwater winter–production and drilling sounds at Northstar were likely audible to ringed seals to ~1.5 km, and that underwater noise from pile–driving activities in Jun and Jul 2000 at Northstar Island were audible to <3 km. Winter activities did not appear to affect ringed seal density or the use of breathing holes and lairs (Moulton et al. 2003, 2005; Williams et al. 2006), and pile–driving activities did not appear to affect ringed seal behavior near Northstar (Blackwell et al. 2004b). Bowhead whales do not typically occur in the Beaufort Sea in winter and are not likely to occur in the shallow water in the immediate vicinity of ODS during the summer or during fall migration (BWASP MMS 2007; Laurinolli et al. 2008). Northstar is further offshore and in deeper water than ODS, and bowhead whale calls have consistently been recorded near Northstar during fall migration. Bowhead whales are less likely to occur in the Northstar area during summer than fall, although bowheads were recorded well west of Northstar in

Smith Bay in mid–Aug 2007 (Green et al. 2007). Whether these whales summered in the Beaufort Sea or were early migrants is unknown.

Bowhead whales are most likely to occur in nearshore areas of the Beaufort Sea during their westward migration in fall. Intensive multi–year acoustical studies during the fall bowhead whale migration at Northstar Island suggested a subtle offshore displacement of migrating bowhead whales associated with production–related noise (McDonald et al. 2007). Bowhead whale calls and underwater industrial sounds associated with Northstar were recorded. The apparent southern edge of the bowhead migration corridor was estimated to be 0.76 km (0.47 mi) further offshore than it would be normally when tones in the 10–450 Hz bands resulting from industrial activity were recorded 15 min prior to the bowhead call. In 2004, the apparent southern edge was 2.24 km (1.39 mi) farther offshore when tones were present within 2 hr preceding the recorded calls (Richardson et al. 2007). Industrial noise resulted from production activities and vessel support. Vessel contributions to underwater sound levels were likely much greater than those resulting from on–island production activities (Blackwell and Greene 2006), although sound contribution from a hovercraft was considerably reduced compared to similar sized conventional vessels (Balckwell and Greene 2005).

Monthly vessel activity at Northstar Island and ODS for 2006 and 2007 is presented in Table 10.6. Vessel routes to Northstar and ODS are relatively short and localized. ODS is located inside the barrier islands ~15 km (9 mi) west of Oliktok Dock where water depth is slightly over 1 m (3 ft). Water depth increases to ~5 m (16 ft) and 13 m (43 ft) about 6.5 km (4 mi) and 14.5 km (9 mi) north of ODS, respectively. Bowhead whales have not been reported in the immediate vicinity of ODS although 86 bowhead sightings have been recorded within 32 km (20 mi) of ODS (BWASP MMS 2007). Williams et al. (2008) reported sighting four bowhead whales 35 km NNE of ODS during an aerial survey on 3 Oct 2007. Those whales were not likely to have been affected by vessel traffic to and from ODS because the vessel sounds would not have propagated that far.

At current levels noise disturbance associated with offshore oil and gas production are unlikely to have affected bowhead whales or other marine mammal species at the population level. Deflections of migrating whales that have been measured appear to be too small to affect whales energetically by increasing their migration distance and do not appear to have prevented whales from accessing their usual feeding areas. Additionally, deflections that have been measured have not affected the ability of Alaska Native hunters to successfully harvest bowhead whales, as whale quotas in most years have been reached despite various industry operations. Current offshore oil and gas development in the Beaufort Sea is located relatively near shore. Future development further offshore may have the potential to affect migrating bowhead and beluga whales. Sound resulting from vessel traffic associated with offshore exploration and development may have greater potential to impact migrating whales than sound resulting from production activities on islands or offshore platforms. Each new development will add incrementally to the potential for these effects to become great enough to impact whales or the subsistence hunt for whales. There are currently not enough data to quantify long term changes in the sound levels in the Beaufort and Chukchi seas, though in general, average levels of in–water sounds have probably increased with development and increases in vessel traffic supporting these developments.

TABLE 10.6. Number of barges, hovercraft, and crew vessel round trips by month to Northstar Island and ODS, 2006 and 2007. Monthly crew vessel totals for ODS in 2006 are not available.

	BP's Northstar Island						Pioneer's ODS			
	Barges		Hovercraft		Crew Vessel		Barges		Crew Vessels	
Month	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
July	10	3	124	97	1	22	9	32	–	112
August	25	32	114	100	69	41	13	61	–	183
September	25	4	162	36	33	71	13	36	–	198
October	4	1	113	18	3	3	11	0	–	22
Total	64	40	513	251	106	137	46	129	327	515

Non–Oil and Gas Related Vessel Traffic

Various types of barge traffic unrelated to the seismic activities occurred in the Chukchi and Beaufort seas in 2006 and 2007. These activities were conducted by barge companies such as Bowhead Transport, Island Tug and Barge, Seaspan International Ltd., and Crowley Marine Services, in support of villages along the Chukchi Sea coast, and village and industry activities along the Beaufort Sea coast. Kilometers of barge activity were estimated for activities in the Beaufort and Chukchi seas based in some cases on actual schedules of barge trips supplied by barge operators and estimated length of barge routes (Tables 10.7 and 10.8). In other cases the actual barge schedules were not available and vessel traffic was estimated after conversations with barge operators.

Non–seismic–related barge traffic for which records were available in the Chukchi Sea was greater in 2007 than 2006 (Table 10.7). Most of the Chukchi Sea barge traffic was associated with transport of fuel and equipment to villages or transit of barges through the Chukchi Sea to the Beaufort Sea. More barge traffic occurred in the Chukchi Sea in Aug than during other months for both 2006 and 2007. It is likely that the amount of barge traffic in the Chukchi Sea during 2006 and 2007 is typical of levels for most years. Few bowhead and beluga whales are known to occupy the Chukchi Sea during mid–summer and barge traffic in the Chukchi Sea probably has little affect on these species. Gray whales and several pinniped species are more common in nearshore areas of the Chukchi Sea during the summer and some gray whales and seals may be temporarily displaced from preferred feeding or resting habitats by disturbance from barge traffic. However, gray whales and seals likely habituate to vessel traffic and disturbance effects from vessel traffic are likely short term. Future development in offshore or coastal areas of the Chukchi Sea would have the potential to result in increased levels of barge traffic which could result in increased disturbance to marine mammals. However, most marine mammals seem to habituate to vessel traffic and impacts from increased barge traffic in the Chukchi Sea would likely not be significant at population levels.

TABLE 10.7. Estimated number of kilometers of nonseismic–related vessel traffic by month in the Chukchi Sea, 2006 and 2007.

Year	July	August	September	October	Total
2006	537	1611	1074	0	3222
2007	1074	4296	2685	537	8592

TABLE 10.8. Estimated number of kilometers of non–seismic–related vessel traffic by month in the Beaufort Sea, 2006 and 2007.

Year	July	August	September	Total
2006	488	16,381	8461	25,330
2007	244	10,182	3424	13,850

Much more non–seismic–related barge traffic occurred in the Beaufort Sea than in the Chukchi Sea during both 2006 and 2007 (Tables 10.7 and 10.8). Sound levels of vessel traffic recorded in 2007 along the Chukchi Sea coast indicated that small vessel traffic associated with local fishing, hunting and pleasure vessels contributed to in–water noise and Table 10.7 excludes this local traffic. There are no data to quantify whether the use of these vessels has increased or decreased in recent years. Additional sound measurements may help to quantify the contribution of these vessels to in–water sounds.

Most of the barge activity in the Beaufort Sea was related to industry or government activities at Cape Simpson, Lonely, West Dock, and Bullen Point. Some barges transited the Beaufort Sea when sailing to or from Canada, and barges also stopped at Barrow and Kaktovik. Barge traffic in the Beaufort Sea in 2006 was almost 2.5 times greater than in 2007. Much of the reduced barge activity in the Beaufort Sea in 2007 was due to lower levels of activity between West Dock and Cape Simpson. As was the case for the Chukchi Sea, more barge traffic occurred in the Beaufort Sea during Aug than during other months. The difference in Beaufort Sea barge traffic between 2006 and 2007 suggests that annual variability in barge traffic may be great and may depend on the level of industry or other activities.

Some barge activity in the Beaufort Sea between West Dock and Cape Simpson during 2006 and 2007 was monitored by MMOs (Green and Negri 2006; Green et al. 2007). The barge route was generally nearshore following the coastline with the exception of Harrison and Smith bays where the route was further offshore. No cetaceans were recorded by MMOs during 2006, but 38 bowhead, 10 gray, and 2 humpback whales were reported by MMOs in 2007. No cetacean reactions to the barges were reported by MMOs other than that the humpback whales approached the barge and appeared to be curious. Most seals did not display reactions to the barges although ~17% in 2006 and ~6% in 2007 showed strong reaction (i.e., sudden dives, tail slaps), most of which occurred within 30 m (100 ft) of the vessels. The effects of this barge activity on cetaceans and pinnipeds were likely short term and probably did not have impacts that were biologically significant. Increased levels of barge traffic in future years should it occur, may increase the potential for disturbance to marine mammals. However, it is also likely that most marine mammals may habituate to marine vessel traffic with minimal effects. Increased vessel traffic will also increase the potential for vessel collisions with cetaceans. Jensen and Silbur (2004) reported specific information of vessel/whale collision and assembled a worldwide data base on such strikes.

During the 2006 and 2007 open–water seasons, the major contribution to vessel traffic in the Chukchi and Beaufort seas generally resulted from seismic and support vessels during exploration activities, including research vessels during the deployment and retrieval of acoustic equipment and the conduct of marine mammal surveys (Fig. 10.9). Deep seismic exploration was not conducted in the Beaufort Sea in 2006 and the reduced amount of seismic vessel traffic there in 2006 resulted only from shallow hazards and site clearance surveys by the *Henry C*. The estimated amount of general barge/vessel traffic in the Chukchi and Beaufort seas was variable between the two years for which we have data. However, unlike vessel traffic related to seismic operations for which accurate records are available, we do not have complete records for barges and other vessels that may have operated in both seas during both years, particularly for local traffic associated with hunting and fishing activities. For example, smaller boats used for whaling activities during subsistence hunts are not included in the vessel traffic data in Tables 10.7 and 10.8, nor are fishing vessel activities in the Chukchi Sea. Vessel traffic associated with support of offshore developments at Northstar Island and ODS, which included barges as well as smaller crew vessels, was separated from other barge/vessel traffic due to its localized nature.

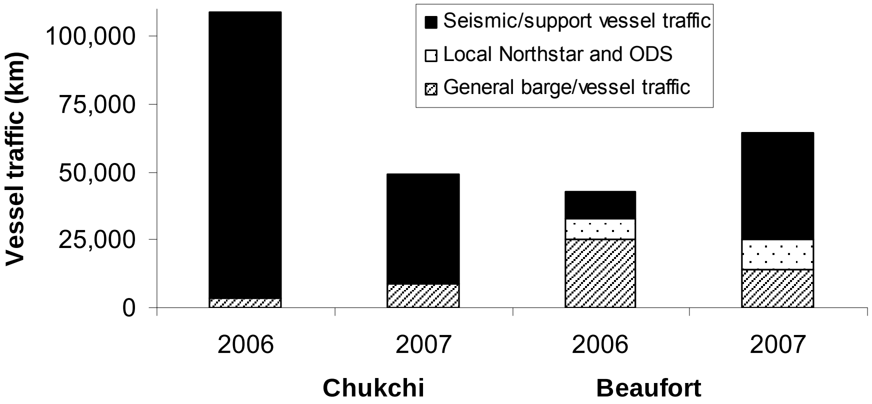

FIGURE 10.9. Estimated number of km of vessel traffic in the Chukchi and Beaufort seas resulting from seismic activities, general barge/vessel traffic, and localized vessel activity associated with offshore developments near Prudhoe Bay, 2006 and 2007.

Commercial Fishing

Relatively little commercial fisheries activity occurs in the Chukchi and Beaufort seas compared to the large fisheries in the Bering Sea, and commercial fisheries in the Chukchi and Beaufort seas probably have little impact on marine mammals. Commercial fisheries in the Bering Sea have the potential to impact marine mammals that spend the summer in the Chukchi and Beaufort but migrate to the Bering Sea for the winter. Impacts to marine mammals could result from collisions with vessels, incidental take, entanglement of fishing gear, and disturbance causing marine mammals to avoid preferred habitats. Commercial fisheries may also compete for some prey species with marine mammals. Commercial trawling has been shown to negatively impact benthic invertebrates (McConnaughey et al. 2000; Dieter et al. 2003) which could affect food availability for benthic–feeding marine mammal species such as gray whale, walrus, and bearded seal. The extent of impacts from current and future commercial fishing activities on marine mammal mammals is unknown.

Research

Vessel–based research has the potential to cause temporary disturbance to marine mammals. Vessel–based research has been conducted to investigate the impacts of climate change on biological, physical, and geochemical processes in the Arctic in recent years (e.g., Cooper et al. 2006; Hardin 2006; Dunton et al. 2007). The activities of these types of research vessels have the potential to cause temporary, localized disturbance to marine mammals. Richardson et al. (1995) reported that noise from vessel activities may have the potential to cause temporary avoidance of specific areas by bowhead whales and other marine mammals.

In addition to seismic activities mentioned above during oil and gas exploration in the Chukchi and Beaufort seas, seismic exploration is also conducted by research groups to study the history of ridges and basins in the Arctic Ocean (e.g., Haley and Ireland 2006). These non–industry seismic activities have the potential to impact marine mammals in ways similar to those discussed above for industry seismic exploration. The level of the impacts would depend on the location of the surveys and the numbers of marine mammals in the survey areas. Warming trends in the Arctic may increase the potential for geophysical research using seismic airguns in the future.

Aircraft are often used to conduct aerial surveys for marine mammals. Numerous industry sponsored aerial surveys for marine mammals have been conducted in support of offshore exploration and development in recent years (e.g., Moulton et al. 2002, 2003, 2005; Reiser et al. 2007; Williams et al. 2008). Industry–supported aerial surveys for marine mammals were conducted in nearshore areas of the Chukchi and Beaufort seas during 2006 and 2007 as part of offshore exploration activities (Funk et al. 2007, 2008). The MMS has also funded or conducted annual aerial surveys of endangered whales in the Beaufort Sea since 1979 (e.g., Monnett and Treacy 2005), and the National Marine Mammal Laboratory has recently begun a multidisciplinary study involving an aerial survey component to study bowheads in a known feeding area northeast of Barrow (Goetz et al. 2007). Aircraft sounds can potentially cause disturbance to some marine mammals although aerial surveys are generally conducted at altitudes sufficiently high that in–water sound propagation from aircraft likely has little impact on marine mammals. Patenaude et al. (2002) reported little reaction of beluga and bowhead whales to fixed–wing aircraft at relatively low altitudes ranging from 60 to 460 m. However, beluga and bowhead whales reactions to low–level helicopters was greater than for fixed–wing aircraft and consisted of various types of changes in behavior.

Pollution/Contaminants

The potential for pollution and contaminants to impact marine mammals and other vertebrate species has been of concern to wildlife managers for many years. Pollution of marine environments may result in increased levels of mortality due to toxic effects or increased levels of disease (Gulland and Hall 2007). Tertiary consumers that are near the top of the food chain are at greater risk than consumers at lower levels due to concentration of contaminants as they progress through the food chain (Wilson et al. 2005). Bowhead whales are secondary consumers that feed primarily of euphausiids and copepods, and the levels of most metals and other contaminants in bowheads appears to be relatively low (MMS 2007; Rosa et al. 2007). Beluga whales and other cetaceans in the Arctic appear to have lower levels of some contaminants than cetaceans from other locations (Norstrom and Muir 1994). Levels of various types of contaminants in arctic seals and walruses have also been measured (Nakata et al. 1998; Fisk et al. 2002; Quakenbush and Sheffield 2007). Some studies have indicated that marine mammals in the Russian Arctic may have higher levels of contaminants that those in the Canadian Arctic (Nakata et al. 1998; Wilson et al. 2005). The effects of current and future exposure of marine mammal populations in the Chukchi and Beaufort seas to various types of contaminants are unknown.

Future offshore oil exploration and development in the Chukchi and Beaufort seas will increase the potential for an offshore oil spill which could contaminate marine mammal food sources. Ingestion of contaminated food sources could be lethal and seals and polar bears could suffer mortality from direct exposure to spilled oil. The potential impacts of an oil spill would depend on the size and location of the spill, the time of year that the spill occurred, and the ability of industry to respond. As is the case for current offshore oil exploration and development, for future offshore oil activities the oil industry would be required to have extensive oil spill response capabilities which would help to reduce impacts from any spill should one occur. It is beyond the scope of this report to describe potential scenarios for oil spill incidents and response, but discussion of these can be found in the EIS documents prepared by MMS for exploration in the leasing areas (MMS 2007).

Climate Change

There has been concern for several decades that the earth may be undergoing global climate changes that impact environmental patterns such as ocean temperatures, extent of the polar ice packs, and weather patterns. Although there still remains some controversy over the causes of climate change, there is now little debate that climate change is occurring and that the effects of these changes are greater at higher latitudes. The potential effects of climate change on marine mammals in the Chukchi and Beaufort seas vary among species. The current warming trend has increased sea–water temperature, and reduced the size of the polar ice cap (Stroeve et al. 2008). Climate change may potentially affect marine mammals in the Chukchi and Beaufort seas in numerous ways and at locations outside of the Chukchi and Beaufort seas. The potential impacts of global climate change on marine mammals in the Arctic may be much greater than those that are likely to result from industrial activities or subsistence hunting.

MMS (2007) describe numerous activities or situations related to global climate change that have the potential to impact marine mammals in the Chukchi and Beaufort Seas. These include factors such as:

- potential changes in the distribution, concentration and availability of marine mammal prey species such as fish, benthic invertebrates, and plankton;
- changes in distributions of marine mammals in response to changes in distribution of prey species;
- impacts to subsistence hunting of marine mammals resulting from changes in marine mammal distribution;
- potential expansion of the ranges of some predators such as killer whales that prey on marine mammal species;
- increased shipping and research vessel traffic through the Northwest passage and other areas of the Arctic which could result in increased disturbance to marine mammals, and the potential for collisions of marine mammals with vessels;
- potential for commercial fishing activities to occur in the Chukchi and Beaufort seas accompanied by increased disturbance from vessel traffic, and potential for marine mammal collision with vessels, entanglement with fishing gear, and possible competition with marine mammals for prey species;
- increased risk of contaminants such as oil or fuel spills from vessel traffic being released into marine environments;
- increased potential for conflicts between humans and polar bears.

Perhaps the most obvious impact to the environment resulting from climate change in the Arctic has been the retreat of the polar ice pack. Stroeve et al. (2008) reported a declining trend in the extent of Arctic sea ice since 1953. The extent of Arctic sea ice declined to an unprecedented low in 2007 which was a 23% reduction from the previous low in 2005. The 23% loss equated to an area approximately the size of Texas and California combined.

Polar bears and ringed seals are year–round residents of the Arctic that rely on the polar pack ice. Ringed seals excavate breathing holes and lairs in the ice which are used for resting, giving birth, and during pup weaning. Ringed seals also use the pack ice for resting during their annual molt. Polar bears feed primarily on ringed seals and female polar bears build winter dens on ice and land to give birth (Bentzen et al. 2007; Bergen 2007; Fischbach et al. 2007). Earlier melting of sea ice in spring may result in exposure of ringed seal lairs making seals more susceptible to polar bear predation, reduce the availability of molting habitat, and result in reduced growth rate and survival of pups. A reduction in the ringed seal population could reduce availability of food for polar bears and affect polar bear survival. Early melting may also have the potential to cause polar bear dens to collapse reducing survival of cubs and adult females.

It is likely that some effects of global warming on polar bears have already been observed. Regehr et al. (2006) reported reduced survival of polar bear cubs in the southern Beaufort Sea region of the U.S. and Canada that appeared to be related to arctic warming conditions. Regehr et al. (2006) also reported a reduction in the body weight and skull size of adult male polar bears captured from 1990 to 2006 compared to bears captured prior to 1990. The smaller stature of adult males was remarkable since it corresponded with higher mean age of the captured male bears. Relatively high numbers of polar bears were seen along the Beaufort Sea coast in 2007. Most of these bears were seen during periods when vessels were not actively working or during aerial surveys. Movement of polar bears to coastal areas has been suggested as an early result of climate warming and has been predicted to increase as the climate warms and the ice pack retreats. The USFWS has recently listed the polar bear as threatened under the Endangered Species Act (USFWS 2008). Newly–released USGS information from nine recent studies presenting the relationships of polar bears to present and future sea–ice environments is available online at http://www.usgs.gov/newsroom/special/polar_bears/.

Changes in the extent of the pack ice will likely result in changes in the distribution and abundance of ringed seals, polar bears, and other marine mammals. Pacific walruses and bearded seals move with the ice edge from the Bering Sea during the winter to the Chukchi Sea (and Beaufort Sea for bearded seal) in the spring and summer. Walruses and bearded seals feed primarily on benthic invertebrates and the ice edge provides them with a platform for resting adjacent to feeding habitat. Pacific walruses and bearded seals probably feed in relatively shallow water to ~80 m (87 yd) in depth although deeper dives have been recorded (Fay and Burns 1988).

Pacific walruses (and possibly bearded seals) are probably more common in the Chukchi than the Beaufort Sea due to the greater concentrations of benthic biomass in the Chukchi Sea (Dunton et al. 2005). Most of the Chukchi Sea is relatively shallow with depths generally <50 m (55 yd) providing extensive feeding habitat for benthic–feeding marine mammals. Pacific walruses normally haul out on ice to rest during the summer in the Chukchi Sea and generally do not haul out on land in large numbers along the Chukchi Sea coast. However, as described earlier, in summer 2007 the pack ice retreated north of the Chukchi Sea into the Arctic Ocean where water depths were much greater and large numbers of Pacific walruses were observed hauled out along coastal locations from Barrow to Cape Lisburne. We suspect that in 2007 the pack ice retreated to water too deep for walrus feeding and that the use of land–based haulouts along the Chukchi Sea coast was an effect of increasing temperatures due to climate change. How the use of land–based haulouts along the Chukchi Sea coast rather than haulout locations on the pack ice will impact walruses is unknown. However, there may be potential for mortality of young walruses to result during stampedes of large walrus groups at land–based haulouts.

The retreating pack may also increase the likelihood of walrus calf mortality due to cow/calf separation. Cooper et al. (2006) reported the occurrence of walrus calves that had been separated from adult female walruses on ice floes in the Canadian Arctic. Pack ice in the area had retreated and the ice floes were located in water depth of >3000 m, well over depths within which walruses are known to feed.

How changes in environmental variables resulting from global climate change are likely to affect cetaceans in the Arctic is unknown; however, some preliminary analyses have found positive correlations between the extent of open water in bowhead whale summer feeding areas and bowhead calf production. Thus, some types of environmental changes may be beneficial to some species while other changes may have negative impacts.

Various types of anthropogenic activities, which are generally thought to negatively impact cetaceans and other marine mammals, are likely to increase in the Arctic if the pack ice continues to retreat. Increased vessel traffic may result from various sources such as oil and gas exploration and development, scientific research, commercial fishing, and increased shipping activity. Increased vessel traffic could increase disturbance to cetaceans resulting in displacement from preferred habitats as discussed above. However, it is not clear that temporary displacement or changes in behavior produce impacts that are biologically significant. Increased vessel traffic would increase the potential for whale collisions with vessels which could result in whale mortality. Commercial fishing could also impact whales through potential entanglement in gear, and trawling activities have the potential to disturb benthic communities that serve as food sources for some marine mammals (McConnaughey et al. 2000).

Increasing temperatures could also result in changes in the distribution and abundance of cetacean prey such as fish, benthic invertebrates, and plankton, which could be beneficial if food availability increased. If prey availability increased further offshore as a result of the current warming trend, bowhead whales may move further offshore during migration and become less available to subsistence hunters. This could produce an overall benefit to the whales but could seriously impact the cultural and social traditions and activities of Native communities.

Other cetaceans not normally found in the Arctic could also extend their ranges northward and compete with arctic cetaceans for food. Sightings of humpback whales and harbor porpoises in the Chukchi and Beaufort seas in 2007 (Chapter 3; Green et al. 2007) may be an early example of such a range extension. Killer whales are known predators on beluga whales as well as on large baleen whales, and increased numbers of killer whales in the Arctic could result in higher predation pressure on beluga and bowhead whales. MMS (2007) concluded that the potential effects of climate change on bowhead whale populations are uncertain, and there is no current evidence of negative effects from climate change on the whales.

SUMMARY

Impacts to marine mammal individuals and populations could potentially increase with expanded exploration and development of oil and gas in the Beaufort and Chukchi seas. Based on the results of a recent sale (6 Feb 2008) of offshore leases, there is clearly interest in further exploration and possible development of oil and gas prospects in the Chukchi Sea. At this time it is not possible to predict how many new developments might occur from future exploration activities. However, it is likely that at least some current prospects would be developed or at least explored to a greater extent in the near future. As additional exploration and development occurs the potential for impacts caused by industrial sounds in the marine environment will rise as will the potential for vessel strikes of marine mammals due to increased ship traffic in the area. Without proper mitigation such impacts could affect marine mammal individuals and result in a decrease in the availability of marine mammals for subsistence use by villages along the coast of Alaska. It appears unlikely that populations of marine mammals would be affected at current levels of exploration although it remains unclear how other types of impacts like changes in temperature across the arctic may ultimately affect these populations and their ability to adapt to additional human influence in their habitats.

Cumulative impacts result from the accumulation of incremental effects resulting from various types of anthropogenic and naturally occurring events. While it is sometimes possible to determine the effects of specific activities or events on individuals or groups of marine mammals, it is often difficult to determine what the effects (if any) may be at the population level or how they may accumulate in individuals over longer time frames ultimately having effects at the population level. Even when data are available which suggest responses of marine mammals to particular stimuli, the responses may also result from numerous environmental variables or naturally occurring cycles in population abundance or distribution. Responses to particular stimuli may be temporary and may not result in effects that are biologically significant. The long term effects of anthropogenic sound that may have the potential to cause deflection of migrating whales from their migratory path or general avoidance of the sound source by marine mammals are unknown. Projections of the potential effects of future activities or naturally occurring events on marine mammal populations in the Chukchi and Beaufort seas are even more speculative than determining the effects of current activities making accurate determination of cumulative impacts difficult.

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